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AND NATURAL GASOLINE MANUFACTURER

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GEORGE REID
Editor

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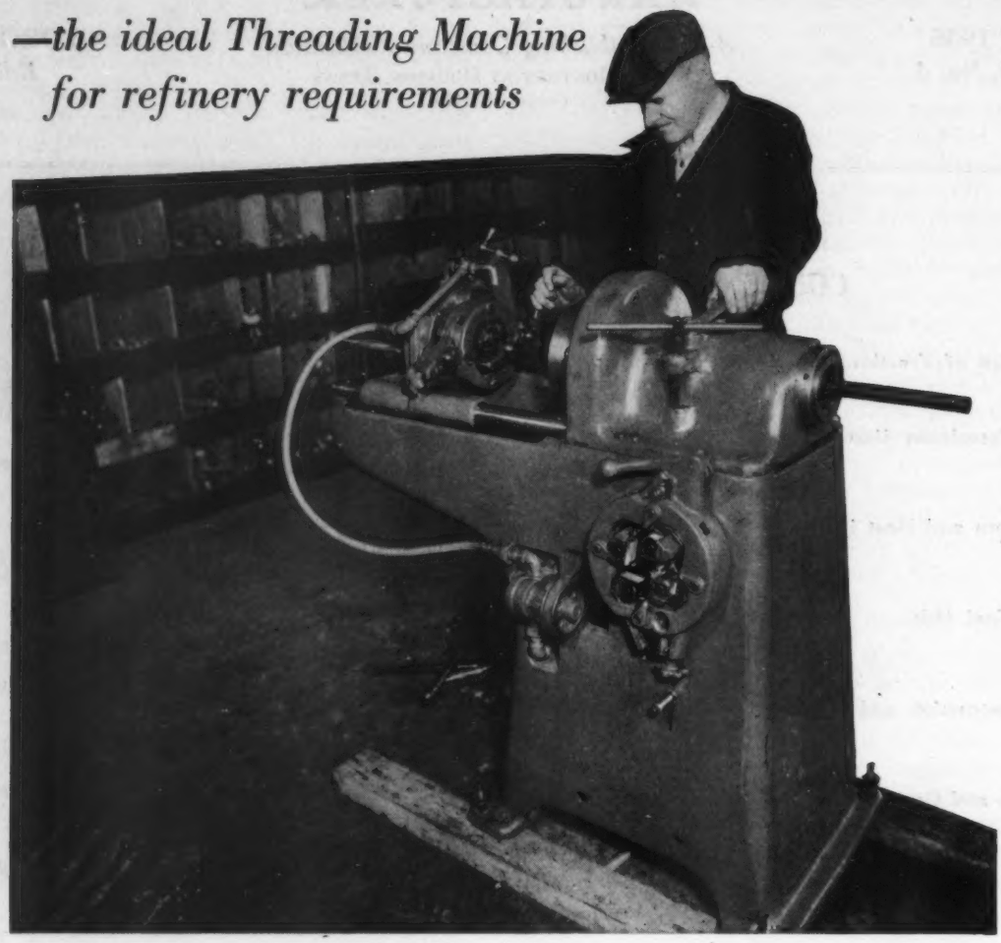

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VOLUME 15, No. 4 APRIL, 1936

REFINER
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The Look Box

THERE is much evidence of the recognized importance of research and experimental work on the part of the petroleum refining industry. Trained workers, engineers, chemical engineers, technologists and scientists are being absorbed by the industry at the rate of over 200 annually. The first survey made by the National Research Council in 1920 listed 117 trained research workers in petroleum laboratories. Subsequent census figures disclose a continued growth of petroleum research indicated by the increasing number of research workers employed in laboratories of the oil company. This upward trend, uninterrupted during the depression, is indicative of the importance assumed by such investigation. It is estimated that today 3200 trained research workers are employed, which is an impressive increase from the modest figure of the 1920 census. The list of colleges and universities offering courses in petroleum engineering is ever growing, and those schools with well established courses and enjoying good repute report that but little difficulty is experienced in placing their trained graduates with oil companies.

Research

In 1920, one commentator states, an estimate of the cost of all refining company research would have been approximately $1,000,000 annually. A fair estimate of money spent at present for research and development work approximates $10,000,000 to $12,000,000 per year—or around $1,000,000 per month.

THE period 1935 to 1940 will apparently be referred to in petroleum refining history as the most active "construction years" in the life of this rapidly developing process industry.

Construction Activity

The period 1925 to 1930 has frequently been mentioned as a very active construction period, for it was during that half-decade that the cracking process became so widely and extensively employed. Domestic production of cracked gasoline during that period increased from 68,000,000 barrels to 164,000,000 barrels annually—and it required a very large number of new cracking units to achieve that result. Since 1930 the increase in production has not been so great.

The period we are now entering will see greater activity in construction, and the total expenditures will be larger. Some commentators are voicing the opinion that in the light of recent technical and engineering development the equipment and processing facilities of the refining industry is from 50 to 60 percent obsolete. A couple of years ago the figure of 35 to 40 percent obsolete facilities was generally accepted.

Now, with improved distillation equipment of all types, improved combination processes, polymerization processes, hydrogenation and dehydrogenation systems, gas pyrolysis processes, and various types of processes for production of a variety of synthetic

products, and improved solvent-dewaxing and solvent-refining processes (some of which will process gasoline) available to the industry, it is possible that the figure of 50 percent obsolete equipment is very fair.

Certain it is that never in the history of the industry has there been so much construction work underway during one short period. Much of it is large installations which will require a year or so to erect. Much of it is under way in this country, but Europe, Asia, South America also are active. The work necessary in this country and abroad can not and will not be attempted at one time. No single year is going to see the obviously needed modernization and expansion completed. The industry is in no financial condition to rectify all its plant ills at one time. The work will be spread out over a period of at least five years, and the total expenditures are certain to be greater than those incurred during any previous period of extremely active construction. And who can say but that in 1940 much of our present most modern facilities may be ready for the scrap heap, not only because of wear and tear and corrosion, but because of still further technical and engineering development and advance?

Process Handbook

THE Process Handbook section of the Composite Catalog of Oil Refinery Equipment, 1936 Edition, published by THE REFINER, is being assembled for publication early this summer. Readers of THE REFINER have been writing in asking for reservation of their copy of the Process Handbook and these requests have been sent to the proper department for handling. The question is often asked as to how the engineer, chemist, superintendent or others in the refining and natural gasoline industry may secure copies of this important and valuable correlation of process information and equipment. Each year THE REFINER publishes advertising calling attention to the Catalog. The coupons appearing with these advertisements should be clipped by those eligible for copies and sent to the address shown thereon.

The distribution of the "Refining Catalog" and Process Handbook, is based chiefly on lists furnished us by the companies owning refineries and gasoline plants.

Material in the catalog section this year is entirely new. The data in the Process Section has been revised and brought up-to-date, and many new processes are included, so that the information does not duplicate that of the previous edition. The material is being presented through the cooperation of 47 refining companies, process owners and construction engineering concerns.

This Issue

INTEREST in the group of Engineering Economics articles inaugurated by THE REFINER with the January 1936 issue, has continued to grow and the response to the efforts of the various contributors has proven most gratifying. In this issue the presentation of such material is continued. W. L. Nelson discusses the important subject of the cost of steam and heat in the refinery; Dr. R. L. Huntington begins a series of articles dealing with natural gasoline plant design and construction; J. S. Walton completes his informative discussion of methods of treating pressure gasoline; and J. A. Campbell contributes a most timely and important article describing the development of a new high-efficiency fractionating plate.

Also in this issue appears two papers from the recent Symposium on Industrial Fuels, held jointly by the Engineers Club and the Philadelphia Section of the American Society for Testing Materials, presented here by special arrangement with the society. These are H. V. Hume's paper on "Industrial Fuel Oils," and W. H. Bateman's paper on "Liquefied Petroleum Gases," and both of these analyses are timely, thorough, and welcome contributions to the literature. V. O. Marshall in his paper before the recent meeting of the Louisiana-Arkansas Refiners Association, dealing with design, construction and operation of heat exchangers presents data which will prove valuable reading to those engaged in working with exchange apparatus.

"Ideas"

THERE is hardly a plant in operation, but that there are some five-dollar bills laying 'round for those that will look closely. Not much has been said in these columns during recent months about THE REFINER's willingness to pay $5.00 for illustrated "Ideas" and $3.00 for those which need no illustrating. That which was published here last year brought in about 100 such items—and more are still coming in. Soon, however, the presses will catch up with the supply on hand, so the offer is repeated this month.

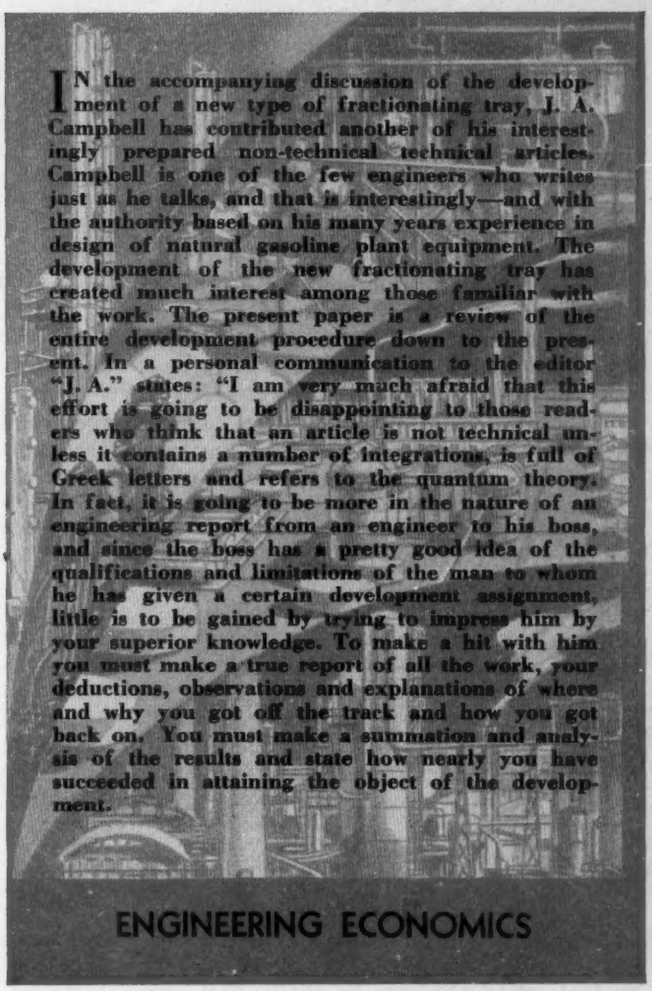
These items may deal with a variety of subjects as has been shown by publication in the department of Ideas from month to month. The illustrations may be drawn in pencil or ink, or the kodak can be brought into service.

Several contributors have received a number of THE REFINER's checks. Others ring the bell once and then nothing more is heard from them. To those let it be said that one five spot does not eliminate them. Look around the plant and see what is new, novel, different, money-saving, more economical, and so on, and try the "Idea" on THE REFINER.

(*Please turn to page 47a*)

A New Design of A Fractionating Plate

J. A. CAMPBELL
Natural Gas Engineer



IN the accompanying discussion of the development of a new type of fractionating tray, J. A. Campbell has contributed another of his interestingly prepared non-technical technical articles. Campbell is one of the few engineers who writes just as he talks, and that is interestingly—and with the authority based on his many years experience in design of natural gasoline plant equipment. The development of the new fractionating tray has created much interest among those familiar with the work. The present paper is a review of the entire development procedure down to the present. In a personal communication to the editor "J. A." states: "I am very much afraid that this effort is going to be disappointing to those readers who think that an article is not technical unless it contains a number of integrations, is full of Greek letters and refers to the quantum theory. In fact, it is going to be more in the nature of an engineering report from an engineer to his boss, and since the boss has a pretty good idea of the qualifications and limitations of the man to whom he has given a certain development assignment, little is to be gained by trying to impress him by your superior knowledge. To make a hit with him you must make a true report of all the work, your deductions, observations and explanations of where and why you got off the track and how you got back on. You must make a summation and analysis of the results and state how nearly you have succeeded in attaining the object of the development.

THE object of this project was to develop a style of fractionating plate which would be universal in application; that is, suitable to absorption, distillation, stabilization and simple contacting, such as washing. It was desired to produce a plate that is more efficient than the plates used at present.

BACKGROUND

If we are starting out to improve something, it is well to have a pretty good understanding of what that something is, and to do that, as in the case of human beings, we learn a lot by checking up on its lineage. So let us turn back the pages of industrial history and check into the equipment used in the first gasoline absorption plants.

The absorbers used in these fore-runners of a great industry were tanks of oil into which the gas bubbled through perforated pipes in the form of spiders. These, of course, afforded single-stage contact and were very inefficient. From here let us trace the evolution of the packed tower through its various stages of improvement to the time where it gave place to the bubble absorber. We must pause here, though, to remark how strange it was that the industry went through all this laborious and costly experimenting with its attendant loss of production when the alcohol industry had, for years, been using well designed and fairly efficient bubbles plates. It is undoubtedly due to the fact that in those days there was little exchange of technical knowledge among the different industries or within the individual industries. There were few technical publications, such as we have today, presenting special articles on equipment development, and devoting their activities to furthering the interests of their respective industries. Moreover, most of the research and development work of this period was conducted in an atmosphere of secrecy such as to make it a violation of company policy for investigators of different organizations in the same industry to get together and compare notes.

However, much of that is behind us, and, thanks to the splendid work of our technical associations and the high-class trade journals which publish and distribute the results of their efforts, much costly duplication has been eliminated, and we are making progress in development which has never been equalled.

The first developers of the absorption process were evidently cognizant that absorption is a function of surface contact, because very early in the game we find them putting into the contact zone foreign matter in various forms to give the oil something over which to film. Into the absorption "tower," as it was called because of its great height, went large quantities of broken rock, steel shavings, brick-bats, bottles and all manner of material selected because it presented a large amount of surface to the down-flowing oil. This surface was supposed to be contacted by the upward-flowing gas. A specially formed molded tile ring proved very popular as did a filler of spirally wound corrugated sheet metal. Later a prevalent form of packing consisted of staggered sections of closely spaced wooden strips.

The objection to all of these forms was that chan-

neling occurred, it being difficult to cause oil and gas to flow in opposite directions through narrow interstices. In order to overcome this difficulty, various redistributing devices were inserted intermediately which to some extent eliminated this channeling. A case in point may well be taken.

At about this stage in the development, the writer was asked by an operating company to check up on the efficiency of one of its plants. It was evident from the outlet tests that the absorbers, 10 in number, and of the wood-grid type, were not properly stripping the gas. Nosing around the bases of the steel shells, he observed that there were warm zones on the surface, readily discernible to touch. This indicated channeling. One of the absorbers was shut down and the head taken off. Resting on the top of the last section of wood grid, about 8 feet down from the top of the 60-foot shell, was a pile of circular sheets of expanded metal lath. The oil spilled on this from a central 2-inch pipe near the top of the shell and its function evidently was to distribute the oil over the wood baffle. These sheets were wired together and were removed as a unit and mounted about a foot above the rim of a circular wash tub. Oil was then poured on the center of the bundle and its inefficiency as a distributor was immediately apparent.

Due to the fact that the sheets had not been rotationally staggered, all the oil came out at one side. It looked simpler to design a more effective distributor than to try to adapt the metal lath, so a cylinder about two-thirds the diameter of the shell was made up and a bumped head with radius equal to its diameter was put in one end. This was generously perforated and a grid covered with two layers of fly screen was put in to prevent these perforations from clogging up with pump packing, etc. This was mounted in the center of the tower under the oil inlet and the tower put in operation. Since a decided improvement in the stripping resulted, all the towers were changed over immediately, with the result that an increase of 2000 gallons per day in plant production was obtained.

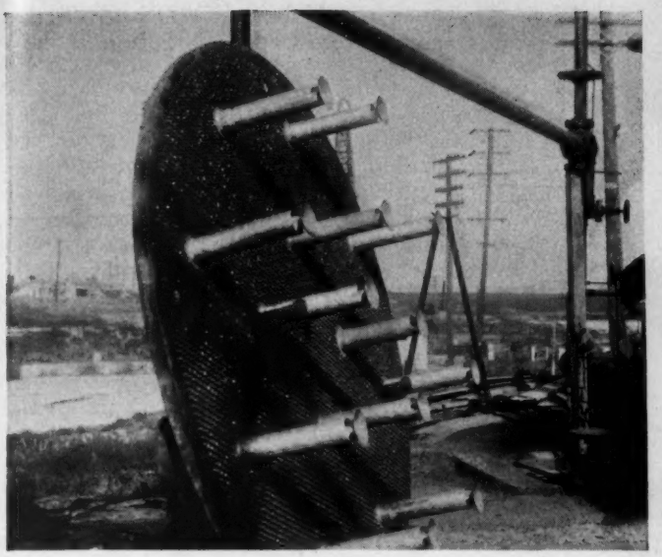
About two days later though, the writer was called to the plant and told that production had dropped below the original figure, and that the steam oil-heaters had dropped 40°; that the pump pressures had built up; the absorbers were carrying over oil; in fact, that the whole plant had gone haywire. Drawing a sample of oil from the system, he was forced to admit that he had never seen absorption oil look so much like rotary mud. It was evident what had happened. This was a flush field, and as is often the case, the gas carried fine sand, particles of rotary mud and rust and scale from pipe lines. This, channeling up through the absorber, deposited on the wood grids, and evidently quite an amount had accumulated. As soon as we had effected more perfect distribution of oil over these grids, this foreign matter began working down, and due to the turbulent flow, was held in suspension in the oil and baked out on the walls of the tubes of the exchangers and heaters until it formed excellent heat insulation. We immediately washed all the oil out of the system and with alternate flushing of steam and cold water followed by gas, we got the system cleaned out and filled up with clean oil. Not only did we get back our original gain in production but an additional 1000 gallons. Later, however, when these towers were replaced with bubble absorbers, an additional 25 percent increase in production was obtained.

In the early stages of the game, the writer had the good fortune to be connected with the research and development division of one of the California major companies, and one of his first assignments was to adapt the bubble cap to absorption. The theory on which we were working was that it would be much more effective and give a shell of a certain diameter much greater capacity if we made the film surface out of the oil itself by creating a mass of bubbles rather than restricting our free area with an accumulation of extraneous material over which to form film surface.

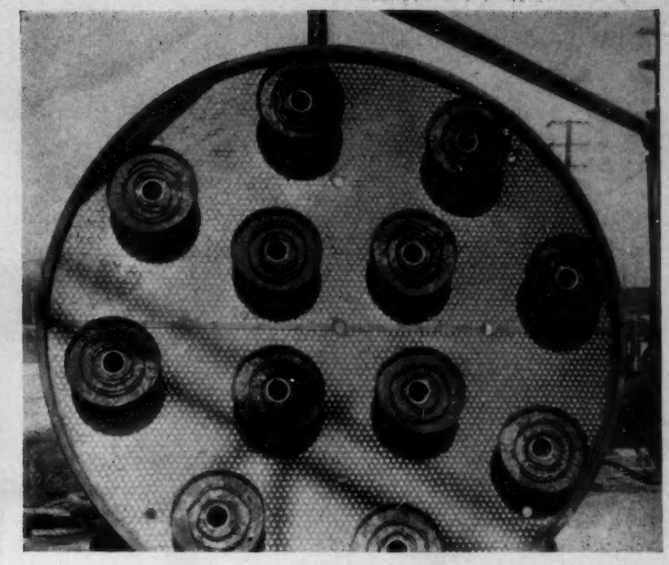
Observing the action on the top plate of the experimental absorber, it was noted the gas broke on the surface of the oil from large bubbles. This, of course, was due to the large ports in the bubble caps. Since a considerable amount of film surface was desired, it seemed to the writer that the logical step was to distort or break up these bubbles into smaller bubbles. This was first tried out in a 500 cc. graduate, feeding the gas to a small bubble cap in the bottom through a brass tube which in turn was inserted through a series of discs cut from fly screen. The observed effect of this was so encouraging that the next moxe was to put a nest of six such screens, spaced one-fourth inch apart by means of glass beads, above the bubble cap of each plate in the experimental absorber.

This gave an increase of about 10 percent in the extraction of gasoline from the gas treated. At this time, there was practically nothing in the way of printed literature of any value on the technical phases of the absorption process, and we had to formulate our own theories and prove or disprove them by cut-and-try methods. Such useful tools as Raoult's and Dalton's laws had not been introduced to the industry, and we knew nothing of fundamental analysis and very little of the physical properties, or constants of the various components of natural gasoline. Very soon, however, we learned that there were six vital factors entering into the absorption accomplishment: (1) Temperature of the lean oil; (2) pressure under which the contact takes place; (3) ratio of oil throughput to gas throughput; (4) time of contact; (5) freedom of the lean oil from fractions to be absorbed, and (6) the intimacy of contact between the gas and the oil. This last is by far the most important of all because so far as concerns any molecule of gasoline in vapor form that passes entirely through the absorber without coming in contact with the film of oil, all the other factions are inoperative.

With this knowledge of fundamentals, we turned to the perforated plate as a means of more thoroughly distributing the gas into the oil and giving us a greater contacting surface of oil film. Now, the perforated plate had been used in other processes but unfortunately some well-known authorities condemned its use both as an absorption plate and as a fractionating plate. Even today many otherwise well-informed engineers contend that a well designed bubble-cap plate will give a higher efficiency than a perforated plate. One well-known authority states that unless the plates are perfectly level, the oil will drop through the perforations on the low side and the gas will pass through those on the high side. Perhaps he is right



Showing back of the rivet plate just before it goes into the absorber. Putting in the 6600 rivets in the 7-foot plate takes the crew about 2 hours, which includes inserting the rivets and spreading the split ends of the shanks.



H. E. Plate assembled with overflow tubes and collector pans in place ready for insertion in the shell of the absorber. Rivets shown here are all seated.

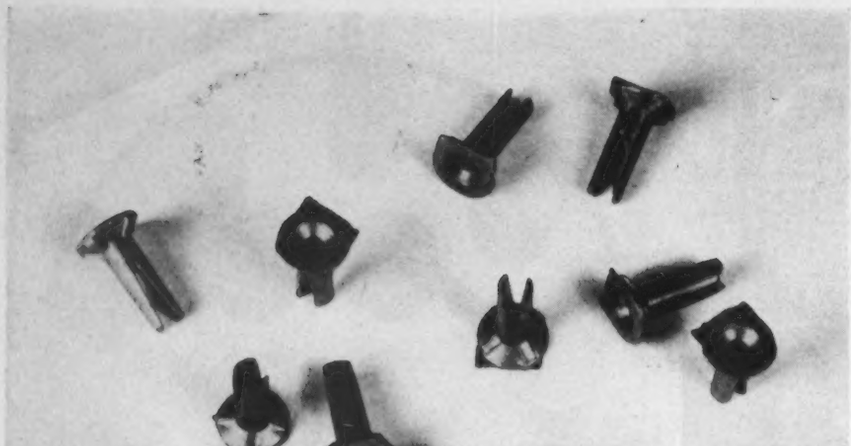
but it would be a poor designing engineer who would not arrange for the careful leveling of each plate, and it is seldom that we see an absorber noticeably out of plumb. A 12-inch glass model of a perforated plate absorber can be tilted while in operation to the extent that the oil is three inches deeper on one side of the plate than on the other and no oil will drop through, even though the gas rate is reduced to 30 percent of maximum capacity. However, we feel confident that considerable oil does drop through the plates of the larger absorbers even at fairly high gas rates, but more of that later.

Let us now analyze the action that takes place in a perforated-plate absorber. To make our example more specific, let us consider a plate 7 feet in diameter with 5/32-inch holes on 1-inch centers, hexagonal drilling. This means that each inside hole is surrounded by 6 other holes each 1 inch away. The overflow tubes, 12 in number and 3 inches in diameter extend 5½ inches above the plate and are surmounted by collector pans 12 inches in diameter and 1½ inches deep, making the froth depth 7 inches. We have learned from the glass model that when running at rated capacity, if we shut off the gas, this settles to 3 inches of oil. Assuming 16 plates to the absorber, we have a total static head resistance of 48 inches of oil, and supposing we use a 39° A.P.I. kerosene distillate as an absorbing medium, this is equivalent to a pressure drop of 1.44 pounds per square inch. Now, by putting the full rating of gas through the absorber with no oil, we get a pressure drop of 0.6 pounds and the total drop through the absorber in full operation is 2.50, so the difference of 0.46 of a pound must be due to viscosity, surface tension or some effect which they produce, such as wetted perimeter of orifices. The oil is prevented from dropping through the perforations, or at least is supposed to be prevented from so doing, by its surface tension and differential pressure across the plate. Since this differential pressure as shown above, is greater than the static head of oil above the orifice, if the surface tension of the oil is great enough to bridge across a 5/32-inch hole, no oil will drop through. However, if we sufficiently decrease the flow of gas through the absorber, the differential becomes less and the surface tension is not great enough to bridge over so wide a gap and oil will drop through some of the perforations. To prevent this, it is necessary to pass enough gas through the plate so that all the perforations are passing gas. It is also necessary that the velocity of the gas through the orifices be sufficient to overcome the static head of oil above the opening or the oil will intermittently "weep" through the hole. It is this occurrence that prevents us from using a fine screen instead of a foraminate plate. The holes cannot be too large else to maintain proper velocity they will have to be spaced so far apart that we get poor distribution. They must not be too small else they may clog up, and to secure proper throughput they will be so close together that the jets will combine and defeat our purpose of securing the ultimate in intimacy of contact. It is desirable to have high velocity jets interfering with each other, for then the oil and gas are more finely broken together, but if there are too many jets such as would be obtained by a screen, the velocity is low and they combine.

Also, regardless of the jet velocity, if the shell velocity is too high there is a loss of efficiency due to too short a time of contact and poor frothing. In some of his first experimental work on absorption, 18 years ago, the writer determined a definite break in efficiency of extraction when a shell velocity of 60 feet per minute was exceeded. This rates a 7-foot absorber operating at 30 pounds pressure at approximately 8 million standard cubic feet per day.

IDEA

What then would constitute the ideal fractionating plate? We realize the importance of a large number of jets to secure intimacy of contact which is in favor of the perforated plate. We desire positive seal so that all the oil on the plate will come in contact with the gas and none drop through, which is in favor of the bubble cap plate. Obviously then if we could devise a plate that would possess both of these features we would have accomplished something worth while. Also, if we could design the jets in the form of small valves that would open proportionally



Details of design of the rivets used in the high efficiency fractionating plates.

to the gas flow, we could maintain relatively high and approximately constant slot velocity and secure a perfect seal at all rates of gas flow. This was the writer's original idea in designing what has developed into the H. E. plate.

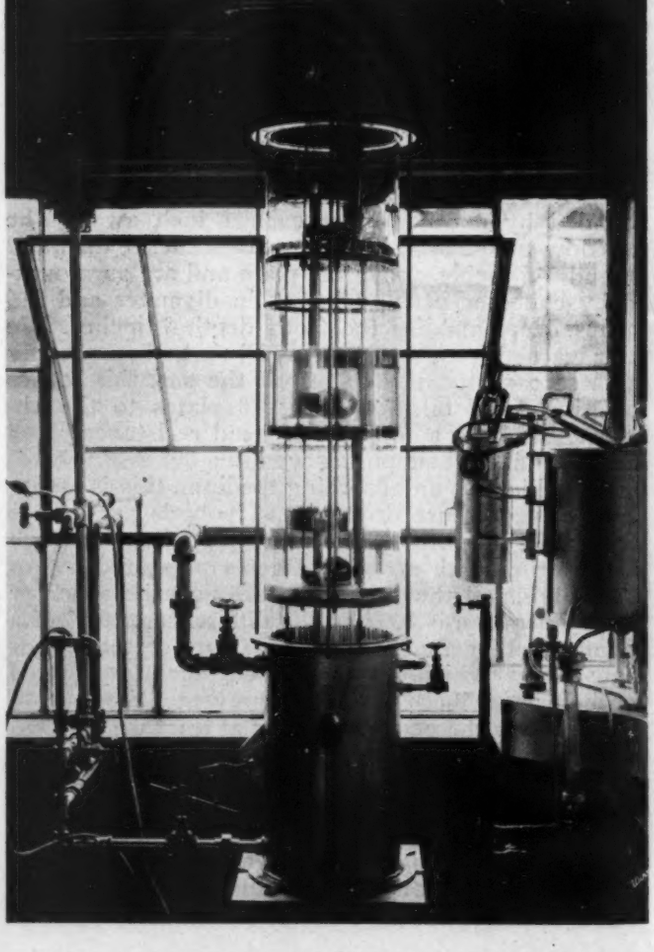
CARRYING OUT OF IDEA

The first step in the experiment was to design a check valve in the form of a conical head split-shank rivet. The head was 3/8 inch in diameter and the shank 3/16 inch in diameter. These rivets are die cast from an alloy of several metals and have the strength of steel, the toughness of bronze, and yet are so light that it takes 350 of them to weigh a pound. We disassembled a standard oil-froth absorber and drilled out the 5/32-inch gas jet perforations to 5/16 inch and a rivet was placed in each hole and the split shanks were spread to prevent them coming out. The absorber was reassembled and put into operation. It was a fine idea but it did not work. Oil carried over badly at about half of its rated capacity.

We operated this absorber with the top head off to study the action and found that instead of the rivets adjusting their lift automatically to the flow of gas, only a few of the rivets would lift and those few to their maximum extent, and all the gas would crowd through these openings. The pressure drop was excessive and the absorber was much given to nausea. The natural conclusion was that the difficulty was due to the static resistance of unfrothed oil above the seated rivets. When a rivet opened, the oil around and above it would be frothed, decreasing this resistance and causing this port to open wide. We assumed that if we could get the oil to froth over the entire plate that the static resistance would be uniform and all the rivets would cut into action.

DETOUR NO. 1

With this reasoning as a guide, we drilled very small holes through the center of each rivet. This, much to our chagrin, increased the capacity only by a small amount and the absorber was still very sick. Checking back over our calculations of slot areas and velocities, weight of rivets, static head, etc., there was absolutely no reason why the absorber should not work and handle its rated capacity unless the rivets were sticking, and what could make them stick in clean oil?



Glass Model with only a few bubbles of gas passing through. Top and bottom plates are perforated oil froth type. Middle plate is rivet-type. Note that oil is dropping through top and bottom plates. On middle plate no oil is dropping back and level is maintained at rim of the overflow. Note displacement and enlargement of down-spouts in middle section due to refraction. Oil on top and bottom plates is about one inch deep, but seven inches deep on rivet plate.

Then we thought of surface tension, and conducting some experiments, we found that it required as much as eight inches of water to break the surface tension between a rivet and plate when the hole was clean and free from burrs.

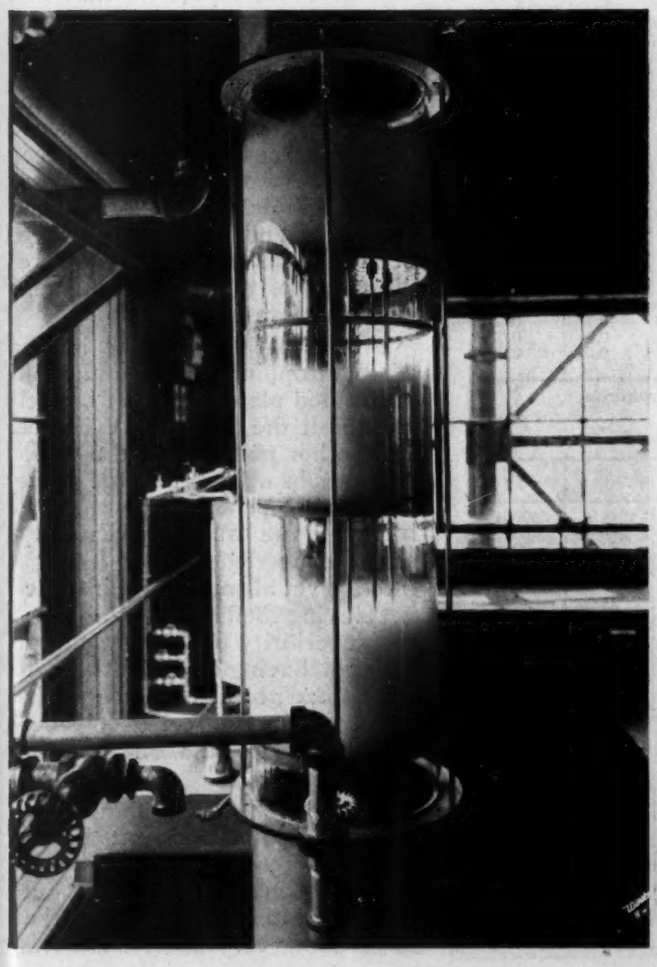
DETOUR NO. 2

After giving the matter considerable thought, it was decided that the best way of eliminating this surface tension effect was to have very slight ribs as elements of the conical surface of the head which would hold the rivet slightly above the plate and allow the gas to break up into thin jets. The number of these ribs was decided as four and their height 1/32 inch. This splits the gas stream coming through each hole into four jets 1/32 inch wide and approximately 1/4 inch long. These jets are directed outwardly at an angle of 30 degrees with the plate. The die was changed and a new set of rivets was cast and installed. When the absorber was put into operation it was in parallel with one of the old-style absorbers and the gas and oil flow were equally divided. A decidedly better extraction was obtained by the rivet absorber as shown by fractional analysis.

We were handling through this particular unit at this time about 8 million standard cubic feet of gas per day and circulating about 400 gallons of oil per minute. While working on the rivet absorber we had put all the gas and oil through the other oil-froth absorber, so after a few days of running both absorbers, we decided to put the entire load through the rivet absorber. Much to our surprise, it became very badly nauseated. We dropped the oil rate and found that 300 gallons per minute was all that it would handle. However, we found that at a rate of 290 gallons per minute we made more gasoline than we did before, circulating 400 gallons. It was difficult to understand why we could not, through a 7-foot absorber with 3-inch over-flow tubes, circulate as much oil as we could through the other absorber identical with the exception of the gas jets, especially when we knew the new jets had greater capacity.

We did notice, however, that although we were extracting more natural gasoline with considerable less oil circulation, we were not making as much liquid petroleum gas. After running at the reduced rate for about two months the demand for this valuable by-product caught up with the supply and we decided to put in 4-inch over-flows in the rivet absorber instead of 3-inch. In doing this we were acting on the theory that considerable oil was dropping through the plates of the oil froth and all the oil in the rivet absorber had to go down through the overflows. With the jets in the new absorber only 1/32-inch wide, the surface tension of the oil is able to bridge over this opening if there is any appreciable gas flow through the absorber. In the old absorber the holes being 5/32-inch in diameter, we are expecting considerable of the surface tension in bridging this gap. By putting

Normal rate through model showing excellent frothing on all plates.



Twenty-five percent of normal rating glass model showing oil dropping to bottom and top plates with level to below overflow. Oil can not drop to middle rivet plate and it must pass the overflow.

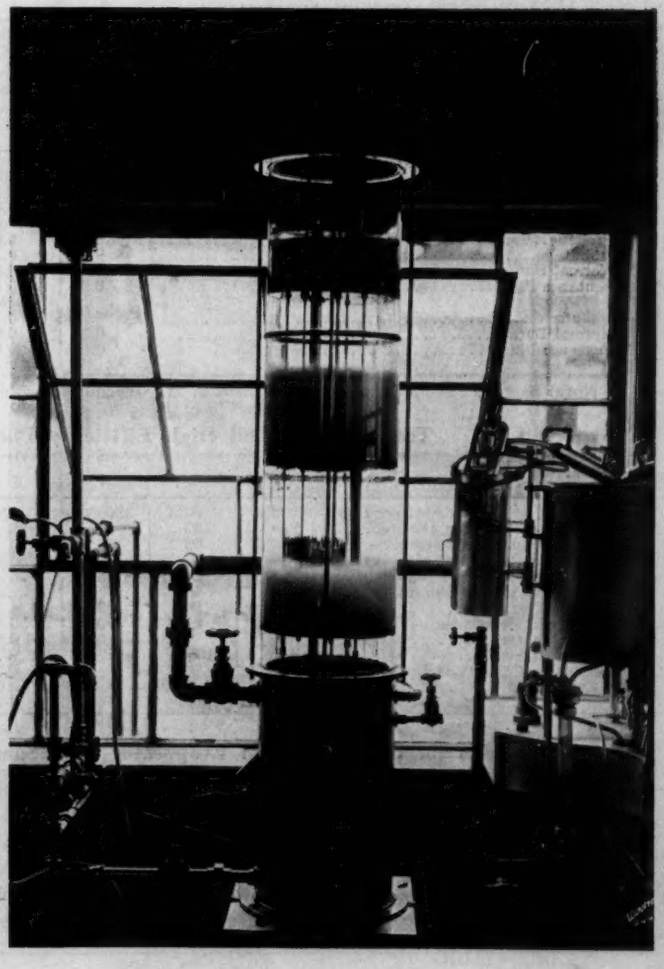


FIGURE 1

Comparative Tests H. E. Plate with Oil Froth Plate

TEST NUMBER	H. E. Plate		Oil Froth Plate		
	1	2	3	4	5
Gas Rate, Standard Cubic Feet per Day	6580M	6300M	6750M	6780M	6590M
Oil Rate, Gallons per Minute	308	178	323	202	145
Oil Temperature to Absorber	80	81	79	72	68
Oil Temperature from Absorber	87	93	86	82	80
Gas Temperature to Absorber	74	74	73	71	70
Oil to Gas Ratio, Gallons per M Cubic Feet	68	40	69	43	32
Pressure in Pounds	34	30	32	32	31
Butane Factor	1.20	.59	1.20	.80	.60
Method of Test	B.W.	B.W.	B.W.	B.W.	B.W.
Outlet Gas Content, Gallons per M Cubic Feet	0.016	0.010	0.016	0.047	0.086
Tests on Lean Oil from Evaporator with Same Plates					
Oil Rate, Gallons per Minute	308	178	323	202	145
Temperature, Oil to Evaporator	334	334	335	338	340
Temperature, Vapors from Evaporator	270	270	265	265	265
Pressure on Evaporator	38	38	38½	36½	36
Lean Oil Vapor Tension, C.N.G.A. Method	0.0	0.1	0.3	0.5	0.0

Analysis of Raw Gasoline Absorbed By

	Oil Froth Plate, Percent	H. E. Plate, Percent
Methane	0.26	0.04
Ethane	1.57	0.96
Propane	15.95	11.49
Isobutane	10.85	8.00
Normal Butane	22.75	21.20
Pentanes Plus	48.62	58.31

Note: Same rates and approximately same operating conditions for both tests.

Comparative Tests H. E. Plate with Oil Froth Absorber

TEST NUMBER	Oil Froth Plate		H. E. Plate	
	1	2	3	4
Gas Rate, Standard Cubic Feet per Day	3825M	4020M	6058M	8500M
Oil Rate, Gallons per Minute	160	195	275	300
Oil to Gas Ratio, Gallons per M Cubic Feet	60	70	65	51

Fractional Analysis—Per Cent

Air	Nil	4.0	Nil	3.50
CO_2	0.4	0.9	0.4	1.10
Methane	89.47	77.58	91.24	76.03
Ethane	3.80	10.06	3.56	10.78
Propane	4.59	6.61	4.22	7.70
Isobutane	0.62	0.40	0.41	0.60
Normal Butane	0.87	0.26	0.10	0.23
Pentanes Plus	0.25	0.19	0.07	0.06
	Gallons per M			
Isobutane	0.20	0.130	0.133	0.19
Normal Butane	0.27	0.082	0.031	0.07
Pentanes Plus	0.09	0.069	0.025	0.02

Note: Samples 1 and 3 Plant A; 2 and 4 Plant B. These plants are in different fields.

Tests on Campbell High Efficiency Plate

TEST NUMBER	1	2	3	4	5	6
Gas Rate, Std. Cubic Feet per Day	4100M	4150M	3960M	3550M	4944M	3500M
Oil Rate, Gallons per Minute	279	162	90	83	90	55
Oil Temperature to Absorber	74	66	63	70	74	69
Oil Temperature from Absorber	80	79	79	86	89	86
Gas Temperature to Absorber	63	64	65	73	78	69
Oil to Gas Ratio, Gallons per M Cubic Feet	100	56	39	34	26	23
Pressure in Pounds	29.5	29.5	29.5	30	30	30
Butane Factor	1.79	1.05	0.61	0.52	0.47	0.38
Method of Test	B.W.	B.W.	B.W.	B.W.	B.W.	B.W.
Outlet Gas Content, Gallons per M Cubic Feet	.007	.003	.003	.005	.007	.028
Tests on Lean Oil from Evaporator with Same Plates						
Oil Rate, Gallons per Minute	279	162	90	83	90	55
Temperature, Oil to Evaporator	340	340	340	340	340	335
Temperature, Vapors from Evaporator	264	264	264	265	264	265
Pressure on Evaporator	37	37	37	37	37	37
Lean Oil Vapor Tension, C.N.G.A. Method, Millimeters	0.8	0.4	0.3	0.5	0.2	0.1

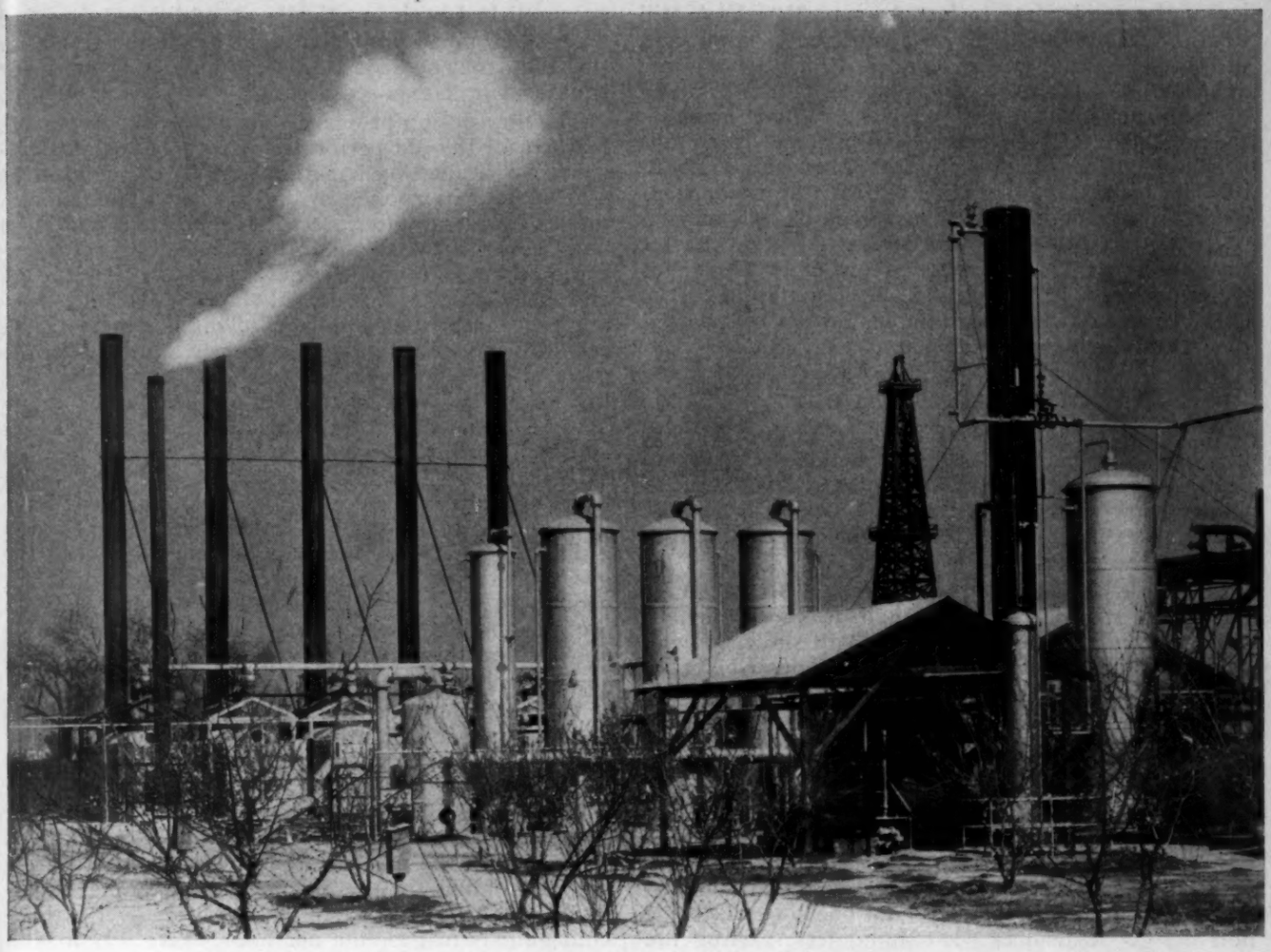
in 4-inch overflow tubes instead of 3-inch you would naturally expect to pass at least 77 percent more oil through the absorber. What we actually accomplished was an increase of 60 gallons a minute from 300 to 360, or a 20 percent increase.

In the face of these results we were forced to conclude that our limiting factor in oil circulation was not the carrying capacity of the down-tubes, but was the froth-breaking capacity of the collector pans. As these pans were as large as we could make them, we saw that it was useless to try to change the design further, so we installed another set of rivet plates in the other shell. After all, 8 million cubic feet of gas per day and 360 gallons of oil per minute is about all we should ask of a 7-foot absorber, operating at 30 pounds pressure.

It is reasonable to assume that increasing the number of gas jets from 6600 per plate to 26,400, that we will create a larger mass of finer froth, especially when the jets are fan-shaped instead of round and are projected laterally so as to interfere with each other. The glass model shows that this is exactly what we do accomplish by using the new plate. The rivets, as observed in the glass model, are in more or less constant motion but there is no evidence of wear. We took one absorber down after six months of operation and definitely established this fact; and why should there be any wear when they are revolving on a film of oil and cushion of gas?

To go further into the matter of oil dropping through the old perforated plates it might be well to submit the following evidence. In another plant, we had a 7-foot oil-froth in operation. Due to increased gas production we had to increase the absorber capacity, so we converted another oil-froth into a rivet absorber and installed it. Having definitely established the superiority of the new design and not having sufficient gas to fully load both absorbers, we gave the rivet absorber considerably more gas and oil than the other.

Fractional analysis showed excessive gasoline content in the combined dry gas, so we ran charcoals on the individual outlets and found the old absorber to be doing very poorly. Leaving



Three 7-foot high efficiency absorbers at Lomita Gasoline Company's Mountain View plant, near Bakersfield, California. Absorbers have been overloaded to over 15,000,000 cubic feet per day, each.

the gas the same, which was approximately in the ratio of two to one, rivet to oil-froth, respectively, we reapportioned the oil so as to give the oil-froth slightly more than the rivet absorber. Production increased and the combined dry gas showed an excellent clean-up and the two absorbers were stripping approximately the same. This convinced us that considerable oil was dropping through the perforation of our old absorber and to get good stripping it is necessary to circulate much more oil than with the new design. This has been borne out in subsequent observations where we have determined that so far as the pentane plus content of the natural gas is concerned we can cut our oil circulation in half with no increase. Less oil circulation means colder oil, and in the design of a plant of given capacity effects tremendous savings. After the above described experience, we promptly changed over the second absorber to the new design.

The rivets are being made in two different patterns, depending on what is to be accomplished. They are cast 100 at a time in a multiple die and when broken off the feeders from the sprue, jagged points are left on the edge of the head. By using the rivet in this form we have established that we get a definite fractionating effect in the absorber, that is by considerably reducing the oil-gas ratio we can strip the gas almost entirely of *iso*-pentane plus, yet leave large quantities of normal butane and lighter. The sharp points are very effective in liberating dissolved gas and extremely volatile fractions. This difference is markedly shown in the analysis of raw gasoline from the old and the new absorber. This liberation and fractionation in the absorber of what otherwise will become uncondensed still vapors, makes the condensers more effective and cuts down the recycle load.

If, however, it is desired to incorporated all the butane in the wet gas in the finished product or to hold it for liquid gas production, we use the cleaned, tumbled rivets. These are the same rivets put through a cleaning die to remove the rough points and then tumbled for several hours in a tumbling barrel to round all the edges and enables us to retain a maximum of all liquefiable constituents with a minimum of oil circulation.

The next logical step in the adaptation of the new plate was to put it in an evaporator, which we soon had occasion to do. The results were uncanny if you are a believer in the theory that vapor tension is a criterion of the degree of stripping of an absorption oil. Personally, I am extremely recalcitrant to the acceptance of this theory. I have always maintained and still do, that this test tells us very little because we do not know which of the various components is responsible for this vapor tension. I much prefer to run a Hemple on the lean oil and judge my degree of stripping by the boiling point curve and by the grav-

ity of the condensate collected up to 370° F. A still better method is to distill off a sufficiently large sample so as to secure enough condensate for a fractional analysis. Be that as it may, believe it or not, many of the vapor tension tests which have been made on the stripped oil, show zero millimeters. It sounds ridiculous, it is ridiculous, but what can you do about it? The tests were made by two of the major companies by methods which are standard with our association and this value was not set down until after repeated trials. One investigator put down a value of .5 millimeter because he said he did not have the nerve to put down zero. Hemples on the oil show it to be extremely well stripped.

OTHER APPLICATIONS

We have adapted the rivet plate to still another purpose. It is being used in a fractionating column in an oil reconditioning plant operating with a feed temperature of 570° F. and is working perfectly. This, however, is getting pretty close to the melting point of the rivets, which is 691° F.

So far we have not had occasion to try out the new plate in a stabilizer but we shall do so at the first opportunity. It is believed that it will show up even better in this service than in those described, because of the low surface tension of the liquids being handled.

SUMMATION

While it is evident that we, as is usually the case in development work, ended up with a different idea from that which we started with, there are decided advantages in the new rivet. With the seated check valve idea, the gas, when it could overcome the surface tension, would tend to go out one side. With the new design, instead of 6600 round jets starting the gas straight up in a spiral bubble, we now have 26,400 fan-shaped jets violently interfering with each other and breaking the gas into myriads of smaller bubbles. This is very noticeable in the glass model which is now assembled with one of the new plates in the middle and an old plate above and below. The turbulence is markedly greater and the froth finer. The jets shoot out and upward through the oil in a parabolic path, the point at which they meet adjacent jets depending on the rate of gas throughput.

The most remarkable thing about the glass model is that as the gas rate is cut down, the oil drops through the old plates and the level in these sections drops to nothing, even with considerable gas pouring through. But not on the rivet plate. Even with just a few intermittent bubbles going through, the oil level is held up to the top of the overflows. Also under these conditions, these few bubbles shift around all over the plate, first coming through one jet, then another.

Another advantage of the new design is the fact that normal rated capacity is attained without lifting the rivets. If a sudden increase of gas is obtained, the rivets lift and the jets are doubled in size, giving the absorber a 100 percent overload factor. This is accomplished with practically no additional pressure drop since the combined weight of all the rivets on the 16 plates of an absorber is only ½ pound per square inch of exposed area.

The new design preserves one of the most valuable features of the old perforated plate; that is, its ability to be cleaned by back-flow. Any type of positive seal plate will sooner or later accumulate enough dirt and muck to interfere with its efficient operation and has to be taken out to be cleaned. By reversing the gas flow through the new plates so that the oil and gas both pass downward through the jets, thorough cleaning is accomplished. This is demonstrated readily in the glass model by merely shutting off the gas and opening a vent below the bottom plate. This breaks the gas seal on the jets and the liquid immediately drains down through all the plates. This is perhaps more readily understood by explaining that each jet is so small that it acts as a capillary. When there is higher pressure below the plate than above it, the surface tension of the oil in the capillary forms a diaphragm in the form of a meniscus between the gas and the oil. When just a few bubbles of gas, not enough to produce turbulence, are passing through the glass model, these menisci are easily discernible as the upwardly convex interfaces between the gas and the oil.

As an example of the ability of the new plate to build up super-saturation in the oil, the following is cited: A few days ago at a gasoline plant equipped with the new type absorber, it was necessary to shut down the distillation unit for two hours. This, of course, entirely stopped the oil circulation. The gas flow through the two absorbers was not interrupted the oil holding on the plates and becoming supersaturated. Although this plant produces over a thousand gallons of gasoline per hour, there was a total loss on the day's production of less than 200 gallons. As soon, however, as circulation was restored and the agitation turned back in the still, production stepped up to so high a rate that the stabilizer pump capacity was exceeded and the evaporator relief valve opened from excessive pressure. It was necessary for the next four hours to run with reduced agitation to maintain proper operating conditions.

The new plate is now in operation in several different plants on gas of widely varying constituency and in every case has demonstrated its high efficiency not only through surprising increases in production but in its ability to do this with materially reduced oil circulation.

We see no reason why the rivet plate may not have a wide application in many other industries including oil refining. The rivets may be made of Monel or stainless steel to resist high temperatures and corrosive conditions and the fact that one design of plate may be used so far as concerns drilling and spacing and size of rivets, has a strong appeal. It is adaptable to extremely low rates, is non-clogging, yet gives an intimacy of contact which can only be effected through the use of a large number of high velocity jets.

Liquefied Petroleum Gas

W. H. BATEMAN
President Solgas, Inc., Philadelphia, Pa.

FROM a rather small beginning in 1922 with an output of 222,000 gallons, the liquefied petroleum gas business has increased to 48,173,000 gallons in 1934. The year 1934 showed an increase of approximately 24 percent over the output of 1933, with 1935 showing promise of a considerably greater increase than that of 1934 over 1933. These figures do not include the large quantities of these gases which are used at the place of production as raw material in the manufacture of solvents, or as refrigerants, fuels, etc.

The greatest increase in the utilization of these gases is occurring in the domestic and industrial fields as shown in the following table taken from the Department of the Interior Mineral Markets Report of May 25, 1935:

Quantities in Thousands of Gallons.

USES—	Propane	Butane	Pentane and Propane-Butane Mixtures	Total 1934	Percent 1934	Total 1933	Percent 1933
Domestic.....	15,236	1,046	1,399	17,681	36.7	16,626	42.7
Gas manufacturing.	326	5,064	900	6,290	13.1	8,318	21.4
Industrial and miscellaneous.....	3,119	19,443	1,640	24,202	50.2	13,987	35.9
Total.....	18,681	25,553	3,939	48,173	100.0	38,931	100.0
	38.8	53.0	8.2	100.0	.....	100.0	.....

Statistics indicate that there are more than 13,000,000 families in the United States who live beyond the gas mains. If only 10 percent of this potential market is secured, the bottled-gas sales will represent a retail value of about $60,000,000 annually, with an investment of over $100,000,000 for gas-burning appliances alone. There are now in excess of 240,000 bottled-gas customers in this country with current sales increasing at an accelerated rate.

FUTURE AVAILABILITY

Liquefied gas produced from natural sources is almost unlimited in quantity. Its greatest handicap at present is one of geographical location which, up to this time, has prevented the widespread use from this source. In the past year commercial operations have been started on the conversion of butane into gasoline. The development of liquefied petroleum gas as a motor fuel might well retard this development although it is still too soon to tell just what effect this development will have upon the available supply of these gases.

Now that the major problems of manufacture have been overcome by refineries, this source is becoming an increasing factor in the supply of these products. As butane is becoming more and more valuable as an ingredient of motor fuel, it is extremely doubtful whether this gas will be available from refineries for a long period of time. However, propane will increase in proportion to the total marketed production of liquefied petroleum gas, as it is not possible to include this material in gasoline as we know it today. The greater production of liquefied petroleum gas from refinery gases will tend to eliminate the problem of distribution which has been a great factor in the industry.

DISTRIBUTION

Bottled gas is available in almost every section of the country, either through bottle filling stations, of the Philgas type, or bulk stations storing bottles, which are filled and shipped from the point of gas manufacture. Liquefied gas suitable for bottled gas use is not manufactured by all of the liquefied-gas producers, as the specifications call for a product of

THE liquefied petroleum gas industry received its initial start from Herman Blau, who developed blaugas in Germany, some 28 years ago. This gas originally was used for lighting, although more recently it has been used for cooking, heating and as fuel for the Graf Zeppelin.

The period from 1910 to 1920 was marked by the spasmodic efforts of various individuals and companies. A. N. Kerr contributed several developments to the growth of the industry during this period and made the first attempt to use dry gas sets similar to those now in use. Starting in 1920 with the entry of the Carbide and Carbon Chemicals Corporation in the business, some real progress was begun. This concern developed Pyrogen for metal cutting and Pyrofax for cooking and water heating. It also developed the first bottled-gas distributing plant located in Greenwich, Connecticut, and did much to popularize the product through national advertising.

The year 1926 brought Phillips Petroleum Company with all the technical facilities of a large oil company into the business. G. G. Oberfell and R. W. Thomas were the outstanding figures in this organization which developed special liquefied petroleum gas tank cars approved by the Bureau of Explosives and the first tank trucks. They also obtained more equitable freight rates and originated the practice of leasing bottled gas sets in the way now common to the industry. Previous to these developments, liquefied gas could not be profitably shipped any great distance.

Skelly Oil Company began to produce liquefied petroleum gases from its gasoline plant gases in 1927, and a year later, Standard Oil Company of California and the Shell Petroleum Company began to manufacture and distribute these gases on the West Coast. Standard Oil Company has been particularly active in the marketing of bottled gas and appliances in the Pacific Coast area.

From this time on the development has been very rapid with the advent of other large companies into the field. It is now possible to produce these gases in almost any section of the country.—

The accompanying paper was presented before the joint meeting of the American Society for Testing Materials, Philadelphia District, and the Philadelphia Engineers Club, in connection with the Symposium on Industrial Fuels, and is published here through the courtesy of the A.S.T.M.

high purity, free from corrosive sulphur compounds and from water.

Practically all of the bottled gas is propane, although some small quantities of butane are used in the warmer sections of this country and in some of the foreign countries where its higher boiling point does not necessitate the application of heat. In France it is a common practice to have a small container in the room in which it is consumed. Practically all of the exports of these gases are shipped out of the Gulf ports, some of it in tankers designed for this type of service. Other shipments have been made in cylinders from Atlantic and Pacific Coast ports to Europe, Africa, Bermuda and the Hawaiian Islands.

The distribution of liquefied petroleum gases for industrial uses has in the past been limited largely to shipment in tank cars of 10,000-gallon capacity. The development of high-tensile-strength steels has, however, given impetus to the use of the tank-truck and it is now becoming common practice to haul relatively small quantities over a considerable distance in this manner. On the Pacific Coast, truck and trailer units are hauling butane approximately 300 miles from the source of manufacture. As propane requires heavier tanks, because of its greater vapor pressure, it has not been economically feasible to haul much greater distances than approximately 100 miles, although longer hauls have been made in emergencies.

QUALITY OF MATERIAL

Specifications:

Among the major producers the specifications of the various liquefied petroleum gas products have been fairly well standardized. The marketing of such liquefied petroleum gas as is not produced to some definite specification, is limited to a number of very small producers. The demand for a product having certain definite characteristics is becoming almost universal now that the purchasers are becoming more familiar with existing specifications and test methods, and their significance. The following specifications are those used by one of the largest producers and marketers of liquefied petroleum gases, for a number of its products:

Specifications for Industrial Propane

The composition shall be at least 70 percent propane and/or propylene by liquid volume.

The vapor pressure at 105° F. as determined by the liquefied petroleum gas vapor pressure method shall not be in excess of 225 pounds per square inch gage pressure.

Not less than 50 percent by volume shall evaporate below a temperature of —25° F. as determined by the open-cylinder weathering test.

The product shall be free of hydrogen sulfide. The flash vaporized product shall not contain total sulfur in excess of 15 grains per 100 cubic feet of vapor, as determined by the test for total sulfur in liquefied petroleum gases.

Specifications for Commercial Propane—G-3A

The composition shall be at least 95 percent propane and/or propylene by liquid volume.

The vapor pressure at 105° F. as determined by the liquefied petroleum gas vapor pressure method shall not be in excess of 225 pounds per square inch gage pressure.

The residue as determined by means of the mercury freezing test shall not be more than 2 percent by volume.

The product shall be free of hydrogen sulfide. The flash vaporized product shall not contain total sulfur in excess of 15 grains per 100 cubic feet of vapor, as determined by the test for total sulfur in liquefied petroleum gases.

Specifications for Commercial Propane

The composition shall be at least 95 percent propane and/or propylene by liquid volume.

The vapor pressure at 105° F. as determined by the liquefied petroleum gas vapor pressure method shall not be in excess of 225 pounds per square inch gage pressure.

The residue as determined by means of the mercury freezing test shall not be more than 2 percent by volume.

The product shall be free of hydrogen sulfide. The flash vaporized product shall not contain total sulfur in excess of 15 grains per 100 cubic feet of vapor, as determined by the test for total sulfur in liquefied petroleum gases.

The degree of dehydration shall be such that the product will pass the standard cobalt bromide test.

Specifications for Commercial Butane

The product shall be composed predominantly of butanes and/or butylenes.

The vapor pressure at 105° F. as determined by the liquefied petroleum gas vapor pressure method shall not be in excess of 75 pounds per square inch gage pressure.

Not less than 95 percent by volume shall evaporate below a temperature of 34° F. as determined by the open-cylinder weathering test.

The product shall be free of hydrogen sulfide. The flash vaporized product shall not contain total sulfur in excess of 15 grains per 100 cubic feet of vapor as determined by the test for total sulfur in liquefied petroleum gases.

Tests:

The following tests, which have in most cases been developed by the industry itself, were prepared in an effort to make the tests as simple as possible and still provide dependable tests which would insure the uniformity and satisfactory quality of the liquefied petroleum gas products sold.

The following tests are the ones in common use today:

1. *Determination of Propylene and Other Unsaturates in Commercial Propane.*—This test is intended as a substitute for the procedure of determining unsaturates by the Orsat or other similar apparatus. The method depends upon the fact that propylene is readily and completely absorbed by 80 percent, or stronger, sulfuric acid, while propane is not appreciably affected by the small amount of acid present. The test is intended for use in estimating the unsaturate compounds in commercial propane and other related products.

2. *Total Sulfur Determination in Liquefied Petroleum Gas.*—This test is satisfactory for all liquefied petroleum gases and also for other fuel gases with perhaps small adjustments on the burners, the method measures sulfur as an acid. Other acidic compounds should not normally occur in the gases to be considered and are not considered in the method, particularly since they may be as objectionable as sulfur and would be classed along with sulfur as undesirable and corrosive substances.

3. *The N. G. A. A. Tentative Method for Determination of the Nature and Extent of Contamination of Commercial Propane with Heavier Hydrocarbon Materials by Means of the Mercury Freezing Test.*—This test is intended for the determination of the nature and extent of the contamination of commercial propane with higher-boiling hydrocarbon materials.

4. *The N. G. A. A. Tentative Method for Determination of the Nature and Extent of Contamination of Commercial Butane with Heavier Hydrocarbon Materials by Means of the Open-Cylinder Weathering Test.*—This test is intended for the determination of the nature and extent of the contamination of commercial butane with higher boiling hydrocarbon materials.

5. *The N. G. A. A. Tentative Method for Determination of Vapor Pressure of Liquefied Petroleum Gas Products.*—This test is intended for the determination of the vapor pressure of liquefied petroleum-gas products.

6. *The N. G. A. A. Tentative Method for the Qualitative Determination of the Water Content of Commercial Propane by Means of the Cobalt Bromide Test.*—This test is intended to give a qualitative indication of the water content of commercial propane. A determination of the amount of water in the vapor indicates directly the saturation of liquid with water. The use of cobalt bromide as an indicator depends upon its property of changing color with changing humidity. The test in itself has been quite satisfactory; however, it was found that the method of sampling is very important if uniform results are to be obtained.

7. *The N. G. A. A. Tentative Method for the Determination of the Specific Gravity of Volatile Hydrocarbon Liq-*

uids.—This test is designed for the purpose of determining the gravities of liquefied gases and other highly volatile products.

8. *The Detection of Relatively Non-Volatile Materials in Liquefied Petroleum Gases.*—This test is for the purpose of detecting materials of volatility similar to that of gasoline and oil in commercial butane. The standard 100-millimeter weathering test may fail to indicate the presence of such substances, even though they occur in concentrations high enough to give considerable trouble in the proper utilization of the butane.

9. *Bomb Corrosion Test for Liquefied Petroleum Gases.*—This test is for the purpose of determining the corrosiveness of commercial butane in a manner equivalent to that used for gasoline in the A. S. T. M. Standard Method of Test for Detection of Free Sulfur and Corrosive Sulfur Compounds in Gasoline (D 130—30).[1] The low boiling point of butane necessitates the use of a closed container capable of withstanding the vapor pressure of butane at the temperature of the test. The use of this pressure container rather than a glass bottle is the only real difference between this test and the gasoline test.

10. *Test for Hydrogen Sulfide in Liquefied Petroleum Gases.*—This method is designed for the purpose of determining the absence or presence of hydrogen sulfide in propane or butane. The vaporized liquefied petroleum gas is tested for hydrogen sulfide by means of the lead-acetate method as described in the National Bureau of Standards *Technologic Paper No.* 41.

11. *Test for Quantitative Determination of Mercaptan Sulfur.*—This test is for the purpose of determining the ab-absence or presence of mercaptans in propane or butane. The terms *absence* or *presence* are employed here in the sense that the mercaptan content is less than or greater than the assigned limits of the test. When mercaptans are present, this test may be used as a means of estimating their concentration. The test is not valid when hydrogen sulfide is present in the gas.

12. *Liter Concentration Test for the Determination of Corrosiveness of Liquefied Petroleum Gases.*—This test is for the purpose of determining the presence of excessive amounts of sulfur or other non-volatile corrosive components in liquid propane. Before this test can have any significance the propane must be sweetened, that is, be made free of mercaptans. It is believed that in order to afford protection against the accumulation of an excessively corrosive residue at any point the test should embody a concentration of the non-volatile components of the propane to approximately 100 fold.

Other Tests.—The foregoing tests, as previously noted, were developed by the industry to meet its particular needs. However, there are four tests, one for the determination of the presence of hydrogen sulfides and three A. S. T. M. tests (Reid vapor test, A. S. T. M. method D 323—32T[2]; distillation test, A. S. T. M. method D 86—35[3]; A. P. I. gravity test, A. S. T. M. method D 287—33[4]) which were designed for use with gasoline and which have been applied to pentane.

In relation to these tests it is interesting to note the formation of the A. S. T. M. Committee D-3 on Gaseous Fuels. Formal organization of this committee was effected in June, 1935. Previously several informal conferences had been held which included representatives of all groups interested in gaseous fuels. These conferences developed the fact that a need existed for standardization of sampling technique, heating value determination, specific gravity measurements and other test methods and procedures of importance to producers, marketers and consumers of gaseous fuels. To date, it has only been possible to effect organization and appoint members of the subcommittees. The main activity will be initially in those subcommittees dealing with collection of samples, measurements of samples, calorific value, specific gravity or density.

We believe that the formation of this committee is a decided forward step and that it will clear up many misunderstandings and controversies.

SIGNIFICANCE OF TESTS

The use of a single-component gas is always more desirable than a product combining several gases. However, certain variations oftentimes make possible lower production costs, which in turn can be passed on to the consumer. Bottled gas requires essentially a single component gas, generally propane, free of water and reactive forms of sulfur. The total sulfur should also be kept as low as possible so as to prevent the formation of gases which might prove injurious to equipment and humans. Partial fractionation of the gases would occur, resulting in a concentration of the heavier hydrocarbons in the bottom of the cylinder, if anything but a single component gas were used. This condition would result in a gradual changing of the thermal value of the gas and the pressure would finally drop below the point of utilization which would leave an unusable residue in the bottom of the cylinder. This is particularly serious in those systems that depend upon refilling the storage container from a tank-wagon on the consumer's premises.

The older type of cylinder was equipped with a very thin copper disk which ruptured if the cylinder pressure became excessive, thus protecting the cylinder. As this disk is very sensitive to corrosion, it is quite necessary to use a non-corrosive gas. The newer type cylinders are equipped with spring-loaded safety valves or fusible plugs, as the Bureau of Explosives has recommended that the older type be changed to meet the preferred designs, consequently, the difficulty with copper disks is expected to pass out of existence.

In bottled-gas sets the pressure to the appliances is controlled through a single-stage regulator which reduces the tank pressure to approximately 11 inches of water. This pressure drop produces considerable refrigeration and if water is present in the vapor, it will freeze on the regulator orifice and finally build up to a point where it will no longer pass gas. Experience has shown that this condition is most prevalent at temperatures ranging from 25 to 35° F.

To assure safe continuous service to the bottled-gas consumer, it was necessary to develop a set of tests which would quickly determine the quality of the gas. For the past two years satisfactory results have been derived from the cobalt bromide test for moisture determination, the mercury freezing test for butane contamination, the total sulfur determination and the corrosion tests. All of these test methods are mentioned under the previous headings.

Industrial plants and other users of liquefied petroleum gas in large volumes are not faced with the same problems as those in the bottled-gas industry, except where they are using the tank as a vaporizer and, even then, the product does not have to meet the bottled-gas specifications. All of the users operating under this scheme are using propane as the fuel. The tests of most value to the manufacturer and consumer of industrial propane are the mercury freezing test showing butane contamination and the total sulfur determination, as certain processes such

[1] 1933 Book of A. T. S. M. Standards, Part II, p. 871.

[2] Tentative Method of Test for Vapor Pressure of Natural Gasoline (Reid Method) (D 323—32T), Am. Soc. Testing Mats., Vol. 32, Part I, p. 765 (1932); also 1935 Book of A. S. T. M. Tentative Standards, p. 762.

[3] Standard Method of Test for Distillation of Gasoline, Naphtha, Kerosene and Similar Petroleum Products (D 86—34), 1935 Supplement to Book of A. S. T. M. Standards, p. 177.

[4] Standard Method of Test for Gravity of Petroleum and Petroleum Products by Means of the Hydrometer (D 287—33), 1933 Book of A. S. T. M. Standards, p. 819.

as bright annealing of non-ferrous metals, particularly copper, brass, etc., are very sensitive to the action of sulfur. For this reason, the total sulfur content of the liquefied petroleum gases must be under 15 grains of total sulfur per 100 cubic feet of vapor and the product must be entirely free of highly reactive forms of sulfur, such as free sulfur of hydrogen sulfide. It was not only necessary to devise test methods for hydrogen sulfide and total sulfur but also for mercaptan sulfur since the presence of mercaptan compounds tends to make inaccurate the results of the corrosion tests. Practically all the liquefied petroleum gases are put through a treating process at the point of manufacture, before being shipped, to assure that the products will pass the corrosion test.

Industrial consumers of propane have, in many cases, found it feasible to draw vapor directly from the tank, allowing the latent heat of vaporization to be absorbed through the walls of the containing vessels. As the consumption at these points is always relatively large in comparison to bottled-gas operations, it is necessary to step the pressure down in two stages which prevents the formation of ice in the regulators if the vapor should contain moisture. One of the most important tests in this type of installation is that relating to composition, such as the mercury freezing test, as it is not particularly desirable to build up a residue of the heavier hydrocarbons, for if this should develop to any large extent it would be no longer feasible to continue vaporizing from the tank.

The industrial plants using butane or butane-propane mixtures almost invariably draw liquid from the tank and supply the latent heat of vaporization with steam or hot water through a tubular or flash-type vaporizer. Slight variations in the gas composition will have little or no effect on the operation. Small amounts of moisture will not affect the operation from the standpoint of freezing difficulties in the regulators. The thermal content and sulfur specifications will normally be the tests of greatest interest, as the consumer probably will want to know his cost per B.t.u., and the nature of the operation may require a low total sulfur content and the absence of reactive sulfur as previously commented upon.

UTILIZATION

Until recently, practically all of the propane has been used to operate kitchen ranges and water heaters. A recent development in this field, on a much larger scale, has been the installation of tanks having a capacity of approximately 1300 gallons from which gas is drawn to operate space heaters, gas ranges, clothes driers, mangles and all the other gas-fired appliances which go along with large estates.

These estates receive 100-gallon tank-truck deliveries of propane. This load is particularly advantageous, as it offers a medium of offsetting the bottled-gas peaks which occur during the summer, as many of the bottled-gas stations and liquefied-gas central plants supply vacation resorts.

Industrial plants now are using propane in increasing amounts. The year 1935 probably will show an industrial propane consumption of approximately 6,000,000 gallons, which represents about 23 percent of the total propane sold. This figure is expected to climb very rapidly, particularly where the plants are drawing their material from refinery sources.

Butane continues to be the predominant figure in the industrial field, as this was the first material offered for use; however, propane has several advantages over butane, such as its lower boiling point, higher octane value, refrigeration qualities and value as a metal-cutting fuel. These advantages are only partly compensated by the slightly lower cost for a butane installation. This lower cost is oftentimes offset where butane is only available in tank-car lots by the fact that propane can be purchased in some areas in tank-truck lots; consequently, the investment for a propane tank will, in many cases, be less than that for one to store butane.

During the past year, industrial applications that showed a particularly noticeable increase are direct-fired air heating for plant space heating and oven heating, metal cutting, atmospheric control, particularly in bright and clean annealing and in gas carburizing. Gas carburizing with these fuels has, in most of the cases, replaced the old pack methods. Propane for cutting operations has shown to particular advantage in those plants that are using fuel supplied through a plant gas system. Small and large scale soldering and brazing applications have increased due to the further development of torches suitable for use with these gases. Considerable interest has developed, particularly on the West Coast, in the use of liquefied petroleum gas as a fuel for internal combustion engines. Operating data show several advantages with these fuels due to their high anti-knock value and the uniform manifold distribution obtainable by their use in a gaseous form.

For the time being, it seems that the use of liquefied petroleum gas for automotive purposes will be confined to those operators whose vehicles are operated on regular runs between points at which fuel storage can be made available. Such operators may be large bus companies who operate from a central terminal or operators who run a daily schedule between two central points. The advantages and simplicity of using liquefied petroleum gases, particularly propane, for the combined use of refrigeration, air conditioning and fuel purposes in general, will afford wider usage as soon as prospective users are more fully convinced of the merits and possibilities of these gases. The shippers of perishable foods, particularly the meat industry, are showing considerable interest in the use of propane as a combination refrigerant and motor fuel.

ECONOMIC ASPECTS

In one application or another, liquefied petroleum gas can be found competitive with all other types of fuel and still have all the inherent advantages of a gas without sacrificing the principal advantage of other fuels, which is chiefly one of availability. Liquefied petroleum gas is now being sold for approximately 5 cents to 10 cents per gallon, f. o. b. the point of manufacture. This price will vary somewhat with the volume, quantity and quality desired. Very little fluctuation in the price is expected, as every refinery is a potential manufacturer and supplier of propane. This fact, coupled with the competitive position of liquefied petroleum gas in relation to other fuels, will prevent the price from seeking much higher levels than those now in effect.

Cost of Steam and Heat *in the Refinery*

W. L. NELSON,
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THE contributions to the group of engineering economics articles which Professor Nelson has presented in *The Refiner* in recent months have been well received. His discussions of operations of Shell stills and tube stills, coking and cracking operations and the present analysis of the cost of steam and heat in the refinery are excellent examples of the type of refinery economics articles which are highly desirable for publication. The reader and user of such data can not help but realize something of the experience, research and work involved in the preparation of such analytical discussions. Steam and heat are obviously the most important items of refinery operation and the proper utilization, conservation and distribution of steam and heat influences the profit or loss condition to a marked degree.

ENGINEERING ECONOMICS

IN any attempt to compare the merits of processing operations from a financial standpoint, the engineer is immediately confronted with the question, "What does power, steam, and heat cost?" The three main items of a plant operating cost are:

(1) Value of products less value of raw stock.
(2) Cost of power and heat.
(3) Cost of labor and supervision.

The first of these presents little difficulty, particularly if the process is studied carefully in the laboratory, or if the market conditions can be depended upon, but items (2) and (3) present difficulty because of the constantly changing economic conditions and because of constant improvements in technology.

The purpose of this discussion is to present comparisons of the cost of generating steam and the cost of absorbing heat in a pipe still for the conditions that exist in petroleum refineries. The author is aware that most engineers have figures in mind for the cost of generating steam, such as 20 to 30 cents per thousand pounds, but in many cases such general figures as these are not satisfactory. In other words, the economic feasibility of a process may depend to a large extent on the cost of power and steam and a range of 50 percent, as given above, may stamp a proposed process as economically sound or economically unsound. Furthermore, plant conditions can be enumerated in which the cost of steam may be as low as 4 cents a thousand pounds and others can be found in which the cost exceeds 50 cents.

STEAM COSTS

In order to select a reasonable steam cost, an analysis of the items which compose the total steam cost is useful. Summarized data from more than 12 refineries of varying size and capacity and situated in different sections of the country are shown in Table 1.

By means of Table 1 it is possible to estimate freak generating conditions. As an example consider an isolated natural gasoline plant. In this case the value of the fuel is almost negligible unless the gas is at a high pressure, and the operating labor is nil because the plant operators also tend the boiler equipment. For such a case, the steam generation cost would consist of only items (3), (4), (5), (6) and possibly (7) and (8). Thus the cost would be in the range of 3 to 4 cents plus chemical treatment and depreciation.

As a further example—consider a plant in a large

TABLE 1
Analysis of Steam Generation Cost.

	Cents per M Based on an Average of 23 Cents	Percent of Regular Charges	Range of Data, Percent	Notes*
Regular Charges				
1. Fuel	17.2	74.7	68–90	44¢ per bbl. † Eff.=65%.
2. Labor, operating	2.6	11.1	6–22	Ave. 90¢ per hr.
3. Labor, maintenance	1.2	5.3	1–6	Ave. 48¢ per hr.
4. Supplies, maintenance	0.8	3.7	0.5–7	.....
5. Supplies, operating	0.9	3.8	0.5–8	.....
6. Electrical power	0.3	1.4	1–2.5	$1.45 per Kwh.
Total	23.0	100.0	71.2–132.5	
Extra Charges				
7. Chemicals for treatment	0.4	1.6	1–2	
8. Depreciation—Dependent on policy, etc.	....	....	.....	

* These are averages based on the refineries studied.
† This is not necessarily the market value of the fuel, it is the interdepartmental charge used in the refinery.

city in which labor costs are 55 cents and $1.00 an hour, the value of fuel is 70 cents a barrel and the steam generating efficiency is 80 percent. The steam generation cost would be approximately—

$$17.2 \times \frac{70}{44} \times \frac{65}{80} + 2.6 \times \frac{100}{90} + 1.2 \times \frac{55}{48} + 2 = 28.5 \text{ cents}$$

This manner of estimating the steam cost is presented in mathematical form in Equation (1).

$$C_S = 25.4 \frac{C_F}{E} + 0.029C_O + 0.025C_M + 2 + 0.12C_T + C_D \qquad (1)$$

C_S = Cost of generating steam, cents per 1000 lbs.
C_F = Cost of fuel, cents per bbl. (or per 6,200,000 B.t.u.)
C_O = Cost of operating labor, cents per hour.
C_M = Cost of manual labor, cents per hour.
C_D = Cost of depreciation, cents per 1000 lbs. steam generated.
C_T = Cost of chemicals for treating water, cents per 1000 gals. of water.
E = Efficiency of steam generation, percent.

In addition the size of the installation may have some effect because the operating labor is almost the same for a large and for a small installation unless the operator also has other duties.

DISTRIBUTION OF STEAM CONSUMPTION

The amount of steam used by each department is useful knowledge because such data make it possible to estimate the total consumption of a plant and to draw comparisons between various methods of conducting the processing. For topping and cracking plants, the steam is utilized as shown in Table 2, and the pounds used per barrel of stock is also shown.

TABLE 2

Distribution of Steam Consumption in Topping and Cracking Plants.

DEPARTMENT	Percent of Total Steam	Stock Handled	Pounds Steam per Barrel of Each Stock
Distillation stills	26.	Mainly crude oil	31.5
Pressure stills	31.5	Fuel oil and gas oil	79.
Treators, agitators, etc.	20.	Gasoline and kerosene	53.
Gasoline recovery	10.5	Gases	60.5*
Loading, yard, storage, etc.	9.	.....	....
Miscellaneous	3.	.....	....
Total	100.0		

* Pounds Steam per 1,000 cubic feet of gas.

The same information concerning complete processing is given in Table 3.

TABLE 3

Steam Consumption in Complete Plants

DEPARTMENT	Percent of Total Steam	Stock Handled	Pounds Steam per Barrel of Each Stock
Distillations stills	38.	Crude and rerun stocks	56
Pressure stills	12.5	Fuel oil and gas oil	101
Treaters, agitators, etc.	5.5	All	...
Filters	7.5	Raw and diluted oils	104
Wax handling	14.0	Wax distillate	277
Gasoline recovery	4.5	Refinery gases	101*
Greases	2.0	.....	...
Loading, yard, storage, etc.	10.5	.....	...
Miscellaneous	5.5	.....	...
Total	100.0		

* Pounds steam per 1,000 cubic feet of gas.

The information given in Tables 2 and 3 may be used to estimate the steam consumption in a particular process or of an entire refinery by means of the following general tabulations:

	Total Steam Used, Pounds per Barrel of Crude	Range of Steam Consumption, Pounds
Topping and cracking processing	151	120–180
Complete processing-residual	210	160–245
Complete processing-vacuum	110	90–135

The rather wide range of steam consumption is due largely to the type of processing that is followed, particularly the relative amount of the reduction that is accomplished by steam and the amount by fire.

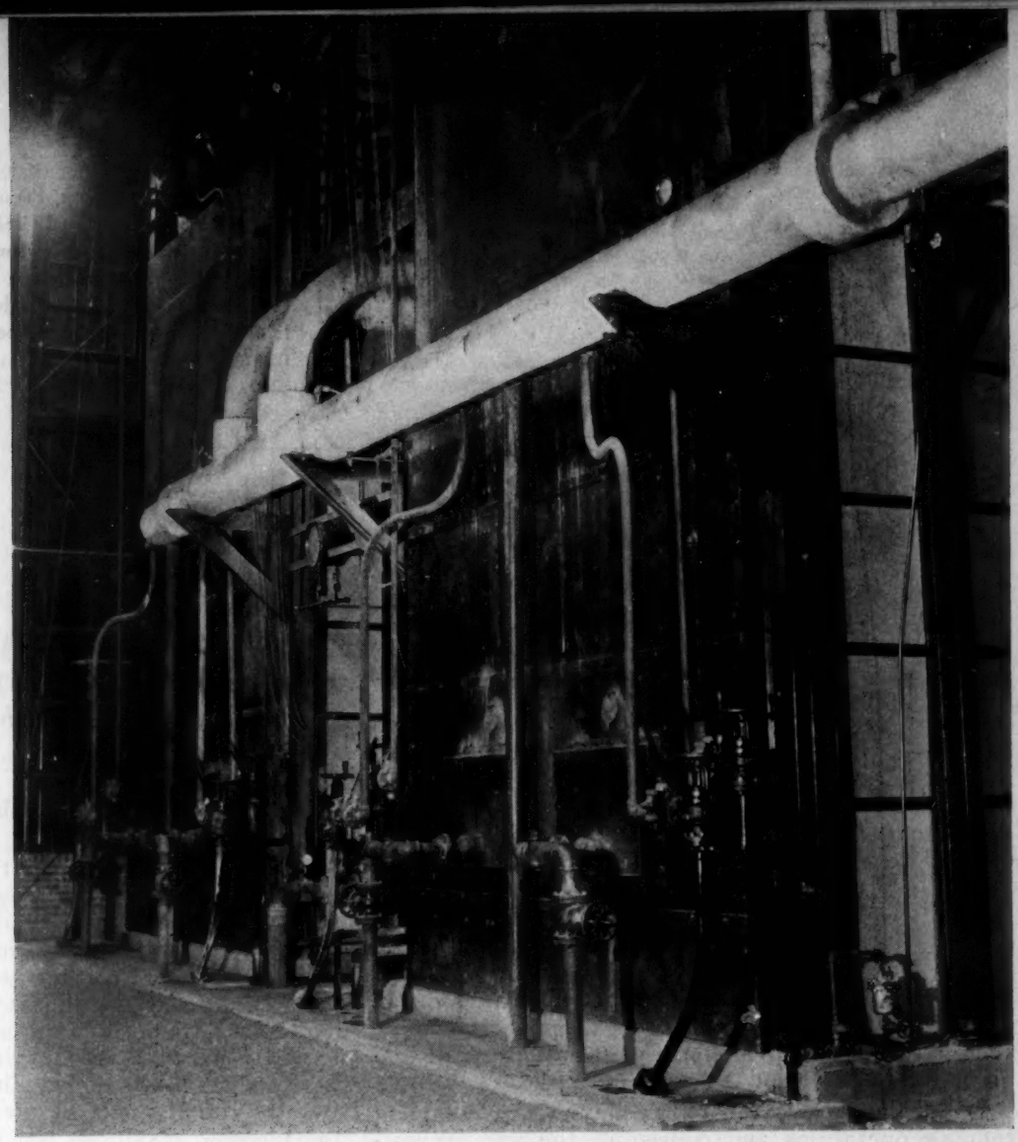
A factor that must not be overlooked in using the above data is the amount of rerunning and retreating that must be practiced not only for stocks that are unsatisfactory upon first handling, but for normal rerunning operations such as the redistillation of pressure distillate, light lubricating oil solutions, and solvent stocks.

EXAMPLE ESTIMATE OF STEAM CONSUMPTION

A crude oil which contains the following raw stocks is to be processed by topping and cracking, (refer to Table 2)—

	Percent
Straight gasoline	30
Kerosene	10
Gas Oil	20
Reduced Crude Oil	40
	100

The approximate yields of intermediate stocks can



be evaluated by means of laboratory analyses[1] etc., and they are somewhat as follows:

	Percent
Pressure distillate	38
Pressure tar	17
Gas and unaccounted for	5

In order to estimate the steam consumption the amount of rerunning must be estimated:

	Percent on crude
Rerunning of crude oil (6 percent)	1.8
Rerunning pressure distillate and gasoline (20%) (due largely to recycling of P. D. butts)	7.6
Distilling crude oil	100.
Distilling pressure distillate	38.
Total distillation stills	147.4
Total treating = 30+10+38×1.2=	85.6

Steam consumption.

	Bbls.	Steam	Totals
Distillation stills	1.47	×31.5=	46.3
Pressure stills	.60	×79. =	47.4
Treaters, etc.	.856	×53. =	45.4
Gaso. recovery	.2*	×60.5=	12.1
Only 88 percent of total (see Table 2)			=151.2
Other uses—12 percent (see Table 2)...			= 18.1
Total steam consumption, lbs per bbl.			=169.3

*200 cu. ft. of gas per bbl. of crude—See Footnote 1.

VALUE OF PIPESTILL HEAT

The cost of absorbing heat in a pipe still is another useful figure. In general the cost of absorbing a million B.t.u. in a pipe still ranges from about 16 to 23 cents plus depreciation. However, such figures are of questionable value because of the constantly changing value of fuel and labor. For these reasons, the following equations, similar to Equation (1) are suggested:

Topping or distillation tube stills

$$C_h = 17.7\frac{C_F}{E} + 0.035C_O + 0.021C_M + C_D + 1.5 \qquad (2)$$

Pressure or cracking stills

$$C_h = 17.7\frac{C_F}{E} + 0.039C_O + 0.05C_M + C_D + 2.2 \qquad (3)$$

in which:

C_h=cost of absorbing heat, cents per million B.t.u.

DISTRIBUTION OF DIRECT HEAT COST

The amount of fuel required to operate a refinery may be measured as a percentage of the crude oil that is processed. For topping and cracking processing the fuel requirement is about 10 percent of the crude oil and for complete processing it amounts to about 12.25 percent. This fuel is used in the several departments of the refinery as indicated in Table 4.

TABLE 4
Distribution of Direct Fuel Cost.

Department	Topping Cracking Processing, Precent	Complete Processing, Percent
Distillation	22	33
Pressure stills	46	31.5
Boiler house	32	35
Earth burning	..	.5

For the fuel prices prevailing in 1933, the direct cost per barrel of crude ranged from about 3.7 cents to 14 cents per barrel.

[THE accompanying discussion is abstracted from a paper presented before the joint meeting of the American Society for Testing Materials, Philadelphia section, and the Philadelphia Engineers Club, in connection with the Symposium on Industrial Fuels, and is published here through the courtesy of A. S. T. M.]

Industrial Fuel Oils

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FUEL OIL has been defined very loosely as "any liquid or liquefiable petroleum product used for the generation of heat in a furnace." Recent developments necessitate extending this definition to cover use in internal-combustion engines, for gas-making purposes, etc. The oils now used as fuels fall into the following classes: (1) crude petroleum, (2) distillate fuels, (3) straight-run residual fuels, (4) cracked residual fuels, and (5) blended fuels.

1. Heavy crude petroleums were formerly used extensively as fuels, but with the development of cracking processes by means of which high yields of more valuable gasoline can be obtained from them, we find only relatively unimportant quantities of asphaltic crude oils, weathered or topped crude oils, such as Venezuelan, Mexican, some Californian and Mid-Continent products being utilized.

2. Distillate fuels are obtained in more complete refining operations and consist of the various portions ranging between crude kerosene and lubricating oils. Since they are all produced by evaporation and subsequent condensation with varying degrees of fractionation, they are clean burning, free from heavy tarry matter, and their use is limited to special applications such as automatic domestic heating plants, some ceramic and metallurgical operations, food processing, etc., where cost is not the primary factor dictating their usage. They may be either straight-run or cracked.

3. Straight-run crude residuals other than those mentioned in the first class are usually found in quantity only in those new sections where flush production makes possible the temporary economic operation of small stripping or topping plants, or in small producing centers where the volume of crude oil produced does not warrant extension of major pipe line facilities. Examples of this are to be found in the East Texas field and in other Mid-Continent areas such as Kansas, Colorado, Wyoming, etc., where the consumption of gasoline and fuel oil produced is largely local. In the refining areas adjacent to large consuming centers, a small quantity of uncracked residual fuel is manufactured for sale to gas-making concerns and other industries requiring a product of special properties, but the premium placed on such products tends to keep the volume low.

4. Residual fuels from cracking operations now make up a large part of the available heavy fuel oils and because of the many economic factors involved will tend to increase in percentage of the total available. Conservation policies tending to reduce the volume of crude oil run for the major product gasoline will help to increase the percentage of cracked fuels.

5. Blended fuels are mixtures of any or all of the above grades in various proportions, and usually are prepared for the purpose of disposing of an excess of one grade or to meet specification limitations such as viscosity requirements where the high viscosity of some types of residuums must be reduced by adding a distillate product. Many of the troubles encountered by users of the heavier grades of fuel oil can be traced to lack of care in blending or of understanding on the part of the refiner or distributor of the possible results in the way of sludge formation when two or more fuels of dissimilar origin or chemical characteristics are mixed.

TESTS

With the rapid expansion of the petroleum refining industry coincident with the increase of automotive units and the steady expansion of fuel-oil burning for heat and power purposes, some standardization of fuel-oil characteristics became necessary since 25 to 50 percent of the crude oil processed is converted to fuel oils. In the early history of the industry it was common practice to classify fuels by gravity, but because of the wide differences in all other properties of fuel oils which are possible when the product is prepared from crude oils of widely different chemical and physical properties, or by cracking procedures of varying intensity, a chaotic condition soon resulted. Oil burners designed to operate on a fuel of 25° A. P. I. available in one district refused to function on oils of similar gravity in other localities. Unfortunately, we still find purchasers of fuel and manufacturers of equipment who insist on gravity specifications, which are undoubtedly the least significant of all factors concerned in the utilization of fuel oils.

In 1928 and 1929 the American Oil Burner Association took the initiative in the preparation of a fairly comprehensive set of specifications, and with the co-operation of the American Society for Testing Materials and the American Petroleum Institute brought out the Commercial Standard specifications for Fuel Oils which have been issued since that time by the Division of Trade Standards of the National

Bureau of Standards. These specifications have been revised from time to time, and in 1934 were published by the American Society for Testing Materials as Tentative Specifications for Fuel Oils (D 396 — 34 T).[1] They conform in substance with the Commercial Standard CS 12-35 of the U. S. Department of Commerce. The requirements of these specifications are listed in Table I, setting forth minimum and maximum values for the most significant features of fuel oils which will guarantee reasonable uniformity for a given grade irrespective of origin of the raw material or type of process used in manufacture.

For equipment design purposes and many special uses, information as to properties other than those included in the above specifications are essential. The following tabulation sets forth all the characteristics which are of appreciable significance in the manufacture or utilization of fuel oils:

1. Flash and fire point.
2. Pour point
3. Water and sediment
4. Carbon residue
5. Ash
6. Distillation
7. Viscosity
8. Gravity
9. Sulfur
10. Thermal value
11. Coefficient of expansion
12. Fouling tendencies

SIGNIFICANCE OF TESTS

Tests for practically all of the above properties have been studied carefully and standardized by Committee D-2 on Petroleum Products and Lubricants of the American Society for Testing Materials and a pamphlet on the Significance of Tests of Petroleum Products was prepared by the above committee and published by the Society in 1934.[1] Brief comments on the above tests taken from this pamphlet and other sources follow:

1. *Flash and Fire Points.*—The flash point of a product may be defined as the temperature to which it must be heated in order to give off sufficient vapor to form a flammable mixture with air. The fire point is that temperature at which an oil will give off sufficient vapor to burn continuously once the air-vapor mixture is ignited. The greatest element of danger in the handling or storage of fuel oils is the explosive ignition of vapors arising from them. As a result there are legal restrictions governing the minimum flash points of the various grades of fuel oil. In many types of installations where automatic ignition is employed, specified flash and fire points are valuable indices of the suitability of a given oil although other tests such as distillation give a better picture.

2. *Pour Point.*—When sufficiently cooled, fuel oils become essentially plastic solids due either to separation of hydrocarbons in the crystalline state or to very high viscosities. That temperature at which an oil will just flow under prescribed conditions is known as the pour point, but since the variations in conditions surrounding the use of an oil cover a wide range of such items as size of container or pipe line, pressure exerted on the oil, structure when solidified, etc., it is obvious that the standard test can only be indicative of what may be expected in service. The test has particular significance in connection with oils that may require heating to liquefy them so they can be pumped, with oils which are fed to the consuming equipment by gravity flow, and in cases where the separation of wax may cause stoppage of lines, filters and orifices.

3. *Water and Sediment.*—The determination of water and sediment in fuel oils is an important one, since many of the heavier fuels are characterized by marked emulsion-forming characteristics. The three most important methods for these determinations are: water and sediment by centrifuge, water by distillation, and sediment by extraction. They are all more or less empirical. The presence of free water is readily detected and this can usually be eliminated with little trouble, but emulsified water frequently resists separation and if present to any extent may cause marked decreases in thermal efficiency, flame failure, foaming in storage tanks or heaters and kindred difficulties. Any appreciable quantity of sediment whether organic or inorganic may lead to the separation of sludge in heaters and storage equipment, stoppage of filters, blocking of nozzles, etc. It is common practice to specify maximum values for these impurities with price deductions made above a certain value and rejection called for at a somewhat higher level.

4. *Carbon Residue.*—When distilled in the absence of air, oils may volatilize completely or leave varying quantities of a carbonaceous residue. When determined by a definitely prescribed procedure this residue is known as "carbon residue." The test was originally developed for use with lubricating oils but has since been applied to fuel oils. There is a fairly direct relationship between the carbon residue of a fuel or gas oil used for gas making and the coky residue left in the carbureting equipment. In some types of oil-burning equipment, the tendency of oils to leave a carbonaceous residue is undesirable because it interferes with ignition apparatus and forms heavy tars in cold boilers. These subsequently coke and act as insulators preventing heat transfer. It is therefore common to find limits established for this property in the manufacturing specifications of many refiners.

5. *Ash.*—While there is no standardized procedure for the determination of the ash content of fuel oils, this characteristic is frequently specified. Any procedure which takes a representative sample of adequate size and avoids mechanical loss during the operation is satisfactory. Ash in petroleum products, except as it may be due to iron rust and dirt picked up from containers or pipe lines or refinery by-products, is only encountered in the heavy products such as residual fuels. Inorganic salts from oil field brines are the outstanding source of trouble in this connection as they may induce erosion of burner tips, mechanical wear in pumps and slagging of refractories in furnaces.

6. *Distillation.*—Tests for determining the boiling range of fuel oils are limited to those of the distillate type and therefore are of little interest to the industrial user. The chief value of distillation tests is found in their use to identify and classify light fuels, and specific requirements are probably essential only in the case of the two lightest distillate fuels commonly vaporized in use. Minimum requirements for the low boiling end of a fuel and maximum limits to the high boiling end insure ready ignition and freedom from carbon-forming fractions of low volatility.

7. *Viscosity.*—The viscosity of a fluid is the measure of its resistance to flow, and since this property changes rapidly with temperature, the latter must always be stated along with the numerical value of the viscosity. Various instruments are used for determining the viscosity of fuel oils but all of them consist essentially of a short capillary tube through which a standard volume of oil at a definite temperature is allowed to flow under carefully prescribed conditions. The time required for such flow is a measure of the viscosity. In this country the Saybolt instruments are largely used, in foreign countries the Engler and Redwood are most commonly encountered. Relationships have been established between the viscosity values of the various commercial instruments which permits the calculation of viscosities in terms of absolute units. Such figures are essential for design purposes in pipe lines, in figuring pump capacities, etc. For a given oil-burning installation there is usually a fairly narrow range of viscosity within which an oil can be pumped most efficiently and another within which atomization is best. By measuring the viscosity of an industrial fuel oil at several temperatures, the thermal rate of change of viscosity can be established and from this the proper temperature of the oil for best efficiency.

8. *Gravity.*—The gravity of a fuel oil is a numerical value indicative of the weight of a measured volume of the product. Two scales are in general use, specific gravity, which in this country is the ratio of weights of equal volumes of oil and water at 60°F., and A.P.I. gravity which is a mathematical function of the specific gravity. It is common practice to sell petroleum products on the basis of volume delivered, corrected to 60°F. Corrections are made from tables showing the magnitude of the correction in terms of the gravity, which must therefore be known. Gravity by itself is of little value as an index of quality of a fuel oil and its use in specifications frequently works to the disadvantage of an uninformed consumer who may limit his supply or be forced to use poorly blended oils by including such a factor. Oil is sold on a volume basis usually, but in an oil-burning system it combines with a definite weight of air for most efficient combustion. The oil is supplied to the burner at a definite volumetric rate per hour, hence if the gravity and therefore the weight of a fixed volume varies the combustion conditions will also vary. This is the same problem as is encountered by the gas industry where natural gas mixed with the manufactured product changes the gravity and requires air-gas adjustments.

[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 34, Part I, p. 882 (1934); also 1935 Book of A.S.T.M. Tentative Standards, p. 696.

9. *Sulfur.*—The quantitative determination of sulfur in fuel oils consists in the complete oxidation of the material and analysis of the oxidation products. Volatile materials are burned in a lamp and the combustion gases analyzed. Heavy products are oxidized in a bomb and the resultant sulfuric acid is determined gravimetrically. Since most fuel oils have a lower sulfur content than coal per unit of heat, the importance of this substance is usually overestimated. Except in certain metallurgical processes or those where flue gases are cooled to temperatures permitting condensation of water with the resultant formation of acids, the sulfur compounds in fuel oil are not harmful.

10. *Thermal Value.*—One of the outstanding advantages which oil can show over other fuels is the high concentration of energy per unit quantity. The thermal value of a fuel is the amount of heat generated in its complete combustion, and is essential information when efficiency studies are being made. Results are commonly expressed as "British thermal units (B.t.u.) per pound" where the B.t.u. is the heat required to raise one pound of water 1°F. Thermal values are determined in a bomp calorimeter and are usually reported as "gross heating values." In actual practice the heat content of steam formed by combustion of hydrogen in the fuel is lost up the stack, since the products of combustion are seldom cooled below 212°F. and the "net heating value" for most industrial fuel oils is approximately 1000 B.t.u. less per pound than the gross value actually determined. Since fuel oil is purchased for its available heat energy, the consumer should be interested in getting the most heat units for his money, but because of misunderstanding of oil properties he frequently writes specifications which defeat his purpose. The common practice of setting a minimum thermal value per pound is undesirable because oil is usually bought on a volume basis. Oils of heaviest gravity have the smallest heat value per pound but more pounds per gallon. For example, an oil of 10° A.P.I. gravity may have 3 percent less heat value per pound than an oil of 20° A.P.I., but have 3.5 percent more energy content per gallon.

11. *Coefficient of Expansion.*—This is a property of oils which does not need determination since it has been connected up with gravity and the relationship set forth in tables prepared by the National Bureau of Standards, but it is of importance where large volumes of oil are heated. Failure to reckon with the expansion of hot fuel oil which approximates 1 percent for each 25°F. has resulted in tanks overflowing, vent line stoppages, and other difficulties.

12. *Fouling Tendencies.*—While no tests have been standardized as yet which will allow the prediction of the sludge-forming properties of fuel oils in storage, this subject is an important one, particularly from the viewpoint of the marine user. The United States Navy is very much interested in this problem and is directly responsible for an active study of all fuel oils commercially available to them. The various research branches of the Naval establishment have made, and are continuing, the most comprehensive study of the burning of fuel oil with which the author is familiar. Both the refiner and industrial user of fuel oil would profit much by a study of the Navy's findings.

In addition to the above properties of fuel oil which have been specifically mentioned, there are many others which are of interest to the designer of equipment for oil burning under boilers or for use in Diesel type engines which are not of direct interest to the industrial user and therefore have no place in this discussion.

UTILIZATION

Except in special cases, the advantages of any particular fuel will not interest an industrial user unless the ultimate cost is less or no greater than the fuel he happens to be using. A discussion of some of the advantages of oil fuel over its chief competitor, coal, leads first to consideration of the relative heat values. The average heat value in B.t.u.'s per pound of coal in round numbers is 13,000 and for oil 18,500. This is the theoretical comparison. In practice, it is impossible to take advantage of all the available heat from either fuel because of inherent differences in possible boiler and furnace efficiencies. The chemical combination of oxygen of the air with the fuel to form oxides is the basic source of heat. If more air is admitted to the furnace than is necessary for perfect combustion, the excess carries heat up the stack and causes the major loss usually encountered. The nature of coal is such that when burned on grates the percentage of excess air above the theoretical is always considerably higher than is the case with oil. As a result, the average combined furnace and boiler efficiency of coal-fired installations seldom exceeds 65 to 70 percent, while with an oil installation in a properly designed furnace the efficiency should not be less than 75 percent and may approach 80 percent in the best installations. Individual instances are on record where both coal and oil have been used under boilers with an efficiency of as much as 85 percent. One reason why it is not possible to approach 100 percent efficiency with oil burning is usually not considered or realized by many users. This is the fact that fuel oil contains on the average 10 to 12 percent of hydrogen which in burning forms water and carries up the stack roughly 7 percent of the available heat as latent heat of vaporization of steam, which cannot be recovered unless the stack gases are cooled below 212°F. This fact is known to designers, however, and is the basis of requests to suppliers of fuel oil to furnish a product of the lowest hydrogen content when it is to be used in a performance acceptance test.

The labor of handling and most of that in firing is avoided by the use of oil. The cleaning of fires and flues is reduced to a negligible item, since there are no ashes or clinkers to contend with, and with intelligent firing there is little deposition in flues and heat transfer is kept at a high level. It is hardly necessary to mention the cleanliness incident to oil firing, as anyone going through a modern oil-fired room might think he was in the engine room.

The ease of transportation and storage of oil is of considerable importance to many users. In marine applications, it is possible to bunker a vessel with oil in almost as few hours as coal might require days, without any of the unpleasantness due to dust, dirt and noise. If we assume, for approximate purposes that 3½ barrels of oil are equal in fuel value to a short ton of coal, then the space required to store oil is only 60 to 70 percent of that of coal. In hand-firing of coal, the working supply must be on the floor and with stoker, in bins overhead, both taking up valuable space other than that used in the main coal bunkers. With oil, the tanks may be buried under the floor or at a distance and, therefore, take up no space that could be used for other purposes.

Where a variable load is encountered, the ease of regulation of oil heat is a vital factor in the economies which can be realized. A turn of a valve will give instant response over a wide range of demand, and in modern installations, furnaces may be kept at essentially constant temperature for weeks at a time. Because of the higher efficiencies attainable with oil, a given boiler can be operated far above its rated steam capacity, which, with coal, would require force draft.

The U. S. Bureau of Mines' figures for 1929 give an interesting picture of the industrial utilization of fuel and gas oils. The following tabulation shows the distribution in millions of 42-gallon barrels:

Steamships	92.0	Textiles	4.7
Railroads	76.0	Chemicals	4.2
Oil refineries	56.2	Cement and lime plants	3.3
Gas plants	21.3	Automotive industries	3.2
Iron and steel	20.3	Paper and wood pulp	3.0
Commercial heating	17.7	Ceramic industries	2.4
Electric plants	10.2	Logging and lumbering	2.2
Domestic heating	7.2	Other manufacturing	13.6
Mines and smelters	7.0	Miscellaneous uses	11.7
Food industries	6.9		
U. S. Navy, Army transports, etc.	6.4	Total domestic	369.5

The largest user of fuel oil is seen to be marine shipping interests. This is probably due to the many advantages of this fuel for that service and to the increasing tonnage of Diesel-powered ships. Railroads particularly in the southwestern and Pacific Coast areas, are the next largest users of oil. Due to the long distance from suppliers of good-quality coal, the elimination of sparks and cinders, which often cause expensive fires, increased mileage at decreased cost and, particularly, the facility with which oil can be adjusted to the fluctuating power demand of such isolated power plants as the steam locomotive, the use of oil for such fuel purposes in this area will probably continue at its present level.

Oil as a refinery fuel will always play a leading role because of the necessity of utilizing refinery residuals which cannot be sold as commercial fuels but which the refineries have learned to use to good advantage. The necessity of having a fuel which is subject to close regulation under the essentially automatic conditions of operation which obtain in modern refinery units demands the use of oil or refinery gas.

In other types of industrial plants, the uniformity of temperature attainable with oil and the resultant increased quality of product are most important advantages. In the case of Naval vessels, particularly desirable advantages of oil are increased radius of action, increased power output, marked decrease in the time required to go from a cold ship to full power, and decreased weight and space required for fuel which is significant in the light of recent restrictions or attempts at restriction of naval armaments.

Any effort to list and describe the various industrial applications of oil burning would entail the writing of a small volume which would be out of place in a paper of this sort. Space might well be devoted, however, to some study of the essential equipment required, which usually includes (1) storage tanks, (2) strainers for removing sediment, (3) pumps, (4) heaters, both line and tank, to raise the oil to proper pumping and atomizing temperatures, (5) piping, (6) meters and temperature-recording apparatus, and (7) burners or atomizers. The main problems of oil burning are, first, the maintaining of a uniform flow of oil to the burners; second, thorough atomizing of the oil, and third, mixing the oil with a proper quantity of air. The solution of any of these depends so much on the individual installation that choice of equipment covers a very wide range of types and capacities. Storage facilities should be adequate to meet plant requirements over the longest probable period between oil deliveries. Duplex strainers are highly desirable so that forced shut downs may be avoided. Pumps, heaters and piping should be of adequate size, entirely tight and free from dead ends. Meters are desirable but not necessary, unless accurate data on fuel consumption are to be obtained. Thermometers are essential for proper regulation.

The most important factor is the choice of a burner adaptable to the type of fuel to be used and to the furnace design. For industrial purposes, there are three main groups, (1) the spray type, in which the atomizing agent is steam or air, (2) the rotary type, in which centrifugal force breaks up the oil and (3) the mechanical type, in which a high-pressure stream of oil is passed through narrow tangential slots preceding an orifice.

The first group is made up of *inside-* or *outside-mixing* types, either of which may use high- or low-pressure air or dry steam. With the *inside-mixing* type, the atomizing agent enters a chamber where it mixes with oil and the mixture in escaping through a small orifice forms a spray due to the expansion of the atomizing agent. In the *outside-mixing* burner, oil under low pressure issuing from a wide slot is sheared by the action of the

TABLE 1

Detailed Requirements for Fuel Oils[a]

GRADE	Flash Point, ° F.		Pour Point, ° F.	Water and Sediment, Percent	Carbon Residue, Percent	Ash, Percent	Distillation Temperatures, ° F.					Viscosity, Seconds			
							10 Percent Point	90 Percent Point		End Point		Saybolt Universal (at 100° F.)		Saybolt Furol (at 122° F.)	
	Min.	Max.	Max.	Max.	Max.	Max.	Max.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
No. 1 — A distillate oil for use in burners requiring a volatile fuel	100 or legal	150	15[b]	0.05	0.02	....	420	....	....	600	....	....	....	....	....
No. 2 — A distillate oil for use in burners requiring a moderately volatile fuel	110 or legal	190	15[b]	0.05	0.05	....	440	620	....	....	600	....	....	....	....
No. 3 — A distillate oil for use in burners requiring a low-viscosity fuel	110 or legal	200	15[b]	0.1	0.15	....	....	....	620[d]	....	....	70	....	....	....
No. 4 — An oil for use in burners requiring low-viscosity fuel	150	....	[c]	1.0	....	0.1	....	....	....	....	....	500	70[e]	....	....
No. 5 — An oil for use in burners equipped with preheaters permitting a medium-viscosity fuel	150	....	....	1.0	....	0.15	....	....	....	....	....	....	....	100	25
No. 6 — An oil for use in burners equipped with preheaters permitting a high-viscosity fuel	150	....	....	2.0[f]	....	....	....	....	....	....	....	....	....	300	100[g]

[a] Recognizing the necessity for low sulfur fuel oils used in connection with heat-treatment, non-ferrous-metal, glass and ceramic furnaces and other special uses, a sulfur requirement may be specified in accordance with the following table:

Grade of Fuel Oil	Sulfur, Maximum, Percent
No. 1	0.5
No. 2	0.5
No. 3	0.75
No. 4	1.25
No. 5	No limit
No. 6	No limit

Other sulfur limits may be specified only by mutual agreement between the buyer and seller.

[b] Lower or higher pour points may be specified whenever required by conditions of storage or use. However, these specifications shall not require a pour point lower than 0° F. under any conditions.

[c] Pour point may be specified whenever required by conditions of storage or use. However, these specifications shall not require a pour point lower than 15° F. under any conditions.

[d] This requirement shall be waived when the carbon residue is more than 0.07 percent and less than 0.15 percent.

[e] This requirement shall be waived when the carbon residue is more than 1.0 percent.

[f] A deduction in quantity shall be made for all water and sediment in excess of 1.0 percent.

[g] This requirement shall be waived when the carbon residue is 4 percent or more.

stream of higher pressure atomizing agent moving usually at right angles to the oil.

Air atomization has the advantage over steam in that there is no additional loss of sensible heat up the stack. The expense of air atomizing, however, is comparable. With steam, the advantages of low first cost of equipment, simplicity and ease of operation are to be balanced against such factors as difficulty with small flames. erratic operation with wet steam and difficulty of close regulation due to high pressures needed, which makes for the use of more steam than is necessary, with consequent losses.

The rotary type burners feed oil through a hollow shaft or other device into a cup revolving at high speed. The oil is thrown off radially in a fine spray and is further broken up or dispersed by a stream of air from a fan which is commonly connected to the same shaft as the cup. This type finds favor for installations in heating plants where the required steam pressure and load are low and where their ease of operation and relatively low first cost are attractive.

In mechanical atomizing burners, the action is due to the motion imparted to oil passing tangentially through small orifices under high pressures (100 pounds per square inch and up) and at elevated temperatures. In addition to the breaking up of the oil because of partial vaporization on the release of pressure of the hot oil and the centrifugal action of the issuing cone of oil particles, a blast of air forced in through registers, in which the vanes are set to give a rotation of their air stream opposite to that of the cone of oil particles, helps to disperse the fuel. With an orifice of a given size, the range of a mechanical burner is limited, as pressure is the only means available for changing the rate of flow, and this does not give sufficient variation for many uses. This limitation of flexibility is not usually very important, because installations are usually multi-burner, and the burning rate can be varied by cutting in or out of one or more burners or by changing to an orifice of larger or smaller size.

This last type is used extensively in marine installations and large land units where high efficiencies are obtained. Among the advantages of this type are absence of high-pressure air or steam lines high efficiencies, shorter flames with resulting smaller combustion space and lower maintenance cost, which are to be considered against less flexibility, more likelihood of clogging of burners and greater expense due to heavier equipment required for higher pressures.

For efficient oil-fired furnaces, the following requirements must be met: (1) Thorough atomizing of the oil, which is a function of burner design, and oil temperature, (2) good mixing of atomized oil with air, which depends on burner type and furnace design, (3) high furnace temperatures for which a certain minimum quantity of refractory furnace lining is required, (4) complete combustion before gases are chilled, demanding ample combustion space, particularly for high rates of firing, and (5) furnace design which will eliminate direct-flame action on refractories or heating surfaces. Failure to consider the above factors in installations which are converted to oil from some other fuel frequently results in inefficient combustion, but where a careful engineering study is made, plants can be revamped to attain all the advantages of oil firing and are often constructed to burn either oil or coal as fuel costs may dictate.

ECONOMIC ASPECTS

The future price trend of fuel oils is an interesting subject for speculation since the market conditions of this class of product are usually more difficult to predict, over even short periods, than are those of gasoline and other lighter fractions. Over the past 15 years the price history of oils used for fuel has fluctuated within a range of about 100 percent, except for fairly short periods of abnormal supply and demand which resulted in variations of one typical grade between $0.40 and $3.50 per barrel. An appreciable fluctuation in seasonal demand, particularly for heating purposes, is usually reflected in changing prices. One of the most significant items affecting the yield and price of fuel oils has been the development of the "cracking" process. In 1920 almost 90 percent of our supply of gasoline was obtained by relatively high-cost topping of crude oil. With the rapid developments in pyrolysis, topped crude residuals became more valuable as raw materials for gasoline than they were as fuel, and in 1930 the yield of cracked gasoline alone was far greater than the total gasoline production a decade earlier. The net result of cracking is to reduce the quantity of crude petroleum required to meet our gasoline demand which also reduces the amount of fuel oil that would otherwise be produced and tends to keep the price from falling so low that is would displace coal in many fields. While topping alone will yield an average of perhaps 20 to 25 percent of gasoline from crude oil, a combination of this process and cracking is today yielding about 45 percent of gasoline and in the most efficient plants the yield is as high as 60 percent.

The increasing demand for gasoline will force the expansion of cracking facilities both for economic reasons and probably for those of conservation, the necessity for which is slowly being brought home to us. The percentage of fuel oil will therefore further decline with no great increase in actual volume to be expected.

If crude oil prices go substantially higher some fuel oil will be taken out of competition with coal, but regardless of price its use in motor ships will increase and the quantity will hold steady in large and efficient steam-driven ships. Higher prices relative to coal will tend to decrease the use of fuel oil by railroads and public utilities, but it is safe to say that for some time to come the price will continue to be in a range where its many advantages such as ease of transportation, smaller storage space, cleanliness, labor saving, ease of regulation, greater efficiency, and capacity will insure its continued use and availability.

Design, Construction and Operation of

Heat Exchangers

V. O. MARSHALL*

J. P. Devine Manufacturing Company

THE process of heat transfer in the oil refining industry is as old as the industry itself. In the early days, a simple pipe coil submerged in a tank filled with water was the only form of heat exchanger necessary, and was used both for condensing the overhead vapor, and cooling the residue from the still.

In those days refining was a very wasteful proposition. Crude oil was plentiful, and the refined products brought a good price, so that a portion of the oil was discarded with little thought of economy.

The development of the automobile increased the demand for gasoline and lubricating oils, and as other products such as tractor fuel, Diesel fuel and furnace oil were developed, the refiners began to realize that the large amount of oil which they were burning in their stills represented a considerable loss of profit.

When the continuous battery replaced the batch still, the way was opened for the recovery of a part of the waste heat. The residuum was discharged through a tank provided with a pipe coil, through which the crude was pumped on its way to the still so that the residuum gave up a part of its heat to the crude. Crude oil transportation cost, increased demand for petroleum products, the constantly increasing demand for higher grade gasoline and motor oil, the apparently rapidly diminishing crude oil supply and the keen competition in the oil industry have made it necessary for the present-day refiner to operate his plant in the most efficient manner possible, so that heat exchangers have assumed a position of major importance in the modern refinery.

Since very little attention was given to their design, the early heat exchangers were very crude and inefficient. It was soon found that exchangers in apparently similar services performed with widely varying efficiencies, and economic necessity soon demanded that engineers study the subject in an attempt to learn what caused the variation, so that the performance of the exchanger could be predicted in advance. In this way, the most economical size and type might be installed, and the refinfier still be assured of satisfactory operation.

These investigations have been conducted by a large number of persons, under widely varying conditions, and the results so correlated that the performance of heat transfer equipment now can be predicted with surprising accuracy. While it is obviously impossible to thoroughly cover such a subject in a short article, the results of the investigations will be briefly outlined.

The three general methods of heat transmission, namely, radiation, conduction and convection, are now well understood.

Radiant heat travels in straight lines in all directions from its source in a manner similar to light.

In fact, radiant heat and light are closely associated, since the more luminous the body, the more heat it radiates. Examples of radiation are the sun, and the

* Read at a meeting of the Technical Group of the Louisiana-Arkansas Refiners Association, Shreveport, Louisiana, March 13, 1936.

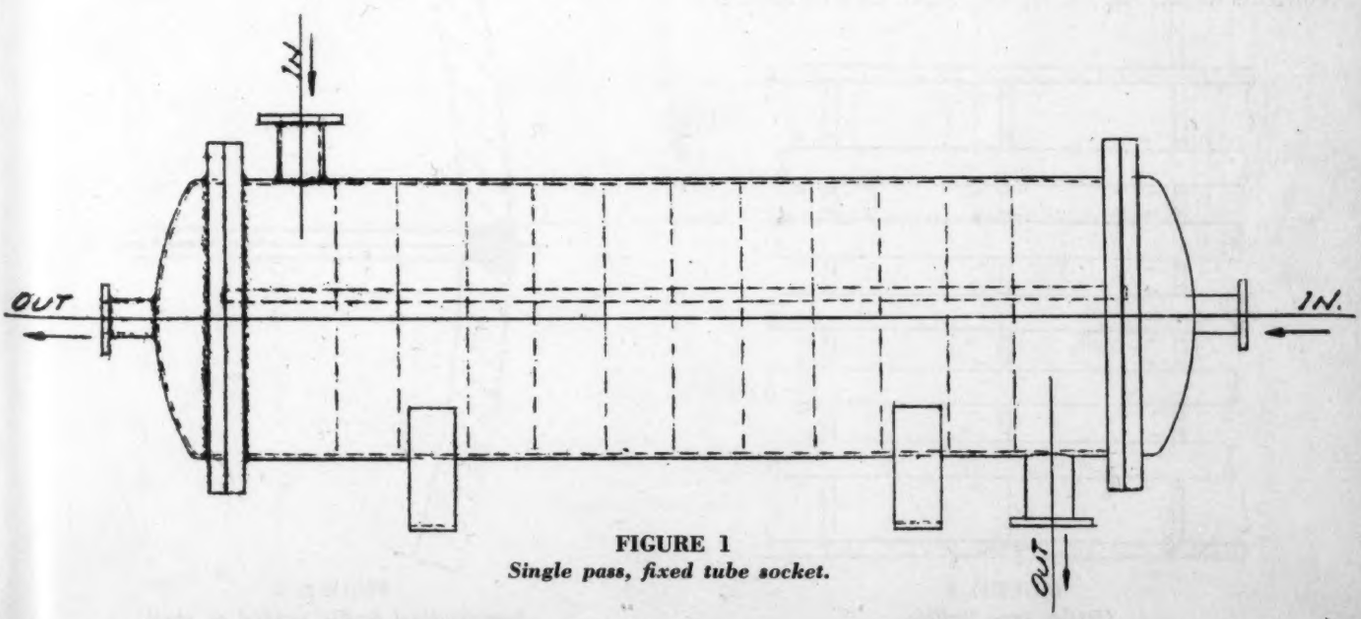


FIGURE 1
Single pass, fixed tube socket.

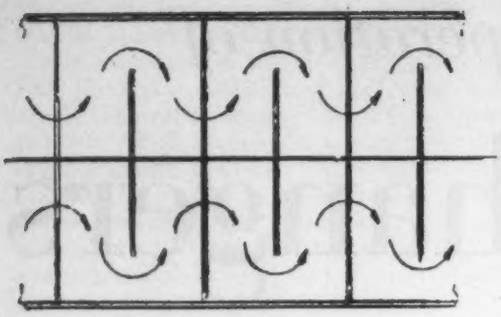


FIGURE 2
Ring and disc baffles.

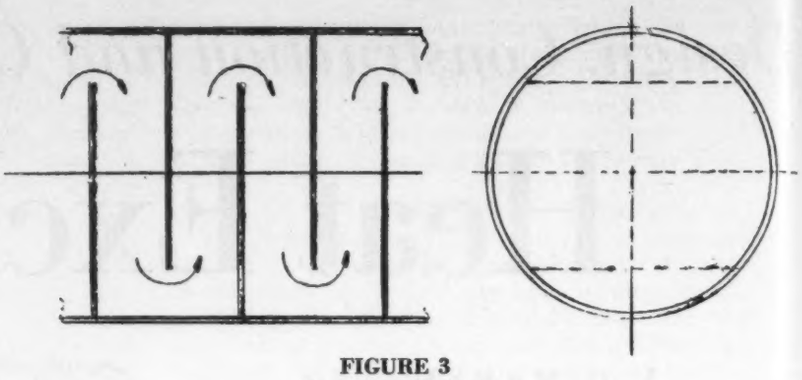


FIGURE 3
Cross flow baffles.

heat from a luminous flame or reflame or refractory surface.

Conduction is the flow of heat through a body by the direct contact of one particle with another. The flow of heat through the brick wall of a furnace, or through the insulation on a pipe are examples of conduction.

The third method, known as convection, is the transfer of heat in a fluid, either liquid or gas, by the movement of the molecules from point to point within the fluid, that is, by a mixing action. Convection may be either "natural," where the movement is caused only by the difference in the temperature of the molecules, or "forced" where they are mixed by some mechanical means, such as a stirring device in a kettle, or the turbulent flow of a fluid through a pipe.

The general equation for heat transfer by conduction is as follows:

$$Q = K\,A\,(\Delta t) \qquad (1)$$

Where Q represents the quantity of heat flowing, per unit of time, K is the coefficient of thermal conductivity of the material through which the heat flows, A is the area taken at right angles to the direction of heat flow and (Δt) is the difference in temperature between the hot and cold surfaces of the material.

Let us assume that instead of passing through one layer of material having a conductivity coefficient of K, the heat must pass through several layers having coefficients of K_1, K_2, K_3, K_4, etc. Since each of these layers of material represents a resistance to the flow of heat, the overall coefficient of thermal conductivity through all of the layers may be designated as "U" and written:

$$U = \frac{1}{\frac{1}{K_1} + \frac{1}{K_2} + \frac{1}{K_3} + \frac{1}{K_4} \text{ etc.}} \qquad (2)$$

The term K in equation (1) will then be replaced by U so that it now becomes:

$$Q = U\,A\,(\Delta t) \qquad (3)$$

In the case of a heat exchanger, the heat must flow from the hot fluid, through the tube wall to the cold fluid.

When any fluid, whether liquid or gas, hot or cold, comes into contact with a solid, as for example, a tube wall, the particles adhere tightly to the solid, forming a so-called film, whether the fluid is at rest or in motion. This film offers resistance to the flow of heat, and in fact is the factor controlling the rate of heat flow, which in turn determines the size of the exchanger.

While it is impractical and unnecessary to measure the thickness of the film, it has been found possible

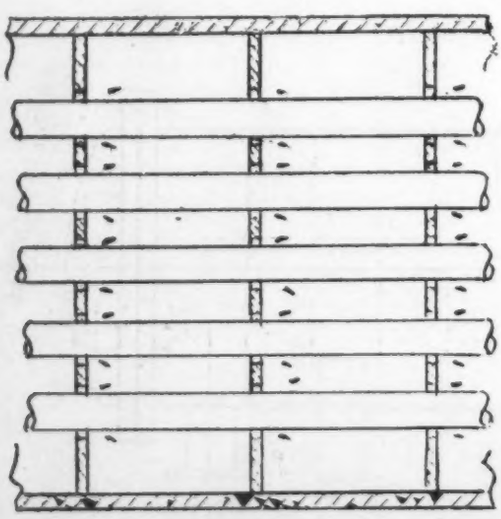


FIGURE 4
Orifice type baffles.

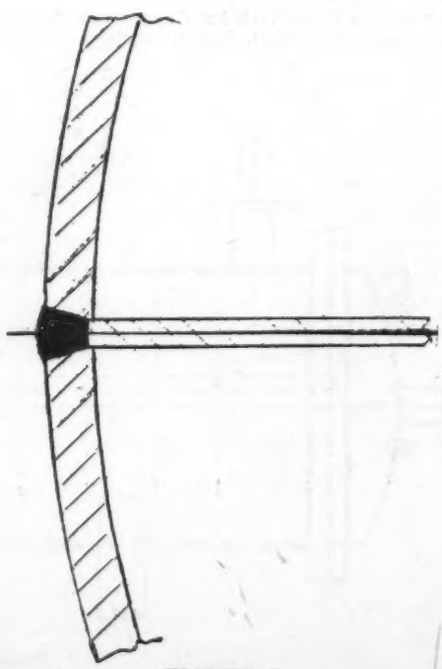


FIGURE 5
Longitudinal baffle welded to shell.

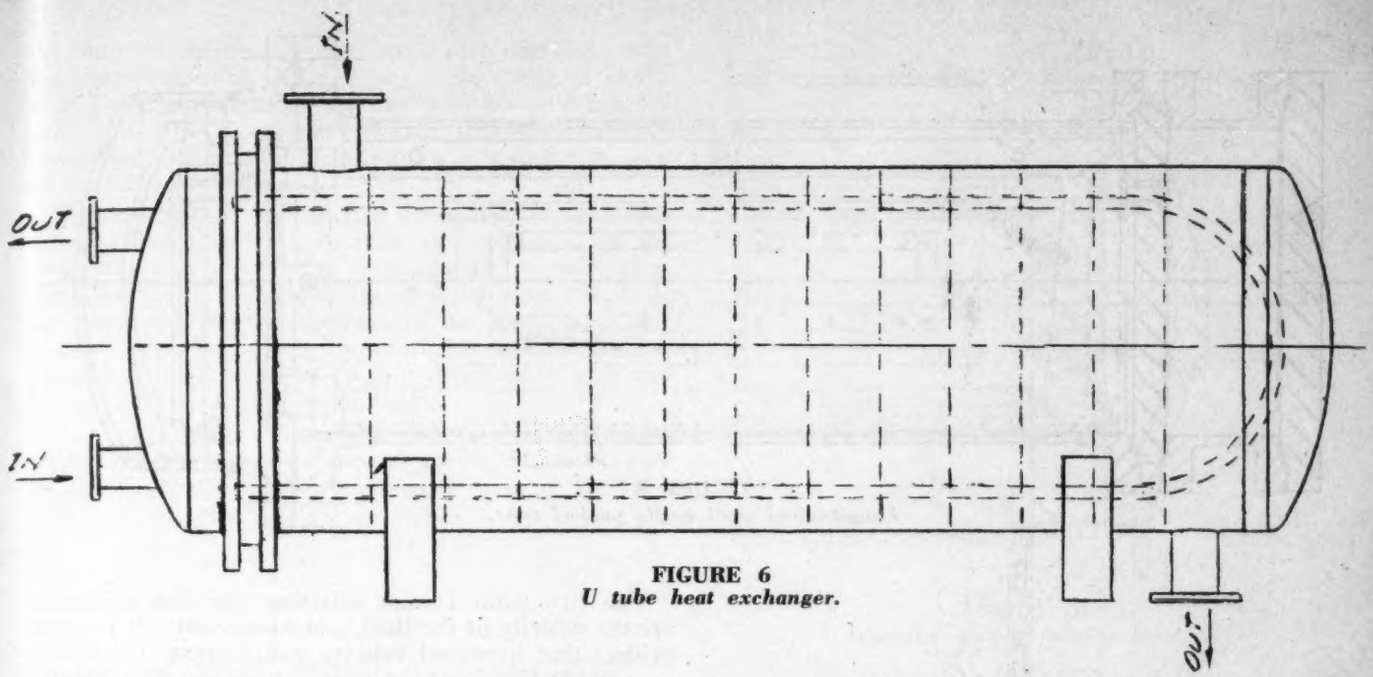


FIGURE 6
U tube heat exchanger.

to calculate its insulating effect, which is usually designated by the letter h, and known as the film coefficient of heat transfer, or simply, the film coefficient.

In a heat exchanger, where the hot fluid flows through the shell space surrounding the tubes while the cold fluid flows through the inside of the tubes, the heat flows from the main body of the hot fluid, through the film on out outside of the tube, through the tube wall itself, and then through the film inside the tube, to the body of the cold fluid. Since the film resists the flow of heat, the temperature drops as it passes through the outside film, so that the temperature of the tube wall is lower than that of the hot fluid. Another temperature drop occurs in passing through the tube wall, and still another in passing through the inside film to the body of the cold fluid.

In equation (3), the value of ($\triangle$t) is equal to the difference in temperature between the hot fluid and the cold fluid. In the most simple form of heat exchanger, the hot fluid enters one end, and flows through the shell to the opposite end, from which it leaves, at a lower temperature. The cold fluid flows through the tubes in the opposite direction, its temperature increasing as it flows from point to point.

For example, the hot fluid may drop from 530°F. to 360°F. while the cold fluid rises from 140°F. to 400°F., as follows:

Hot oil	530	→ 360	
	400	← 140	cold oil
	130	220	

In this example, the difference in temperature between

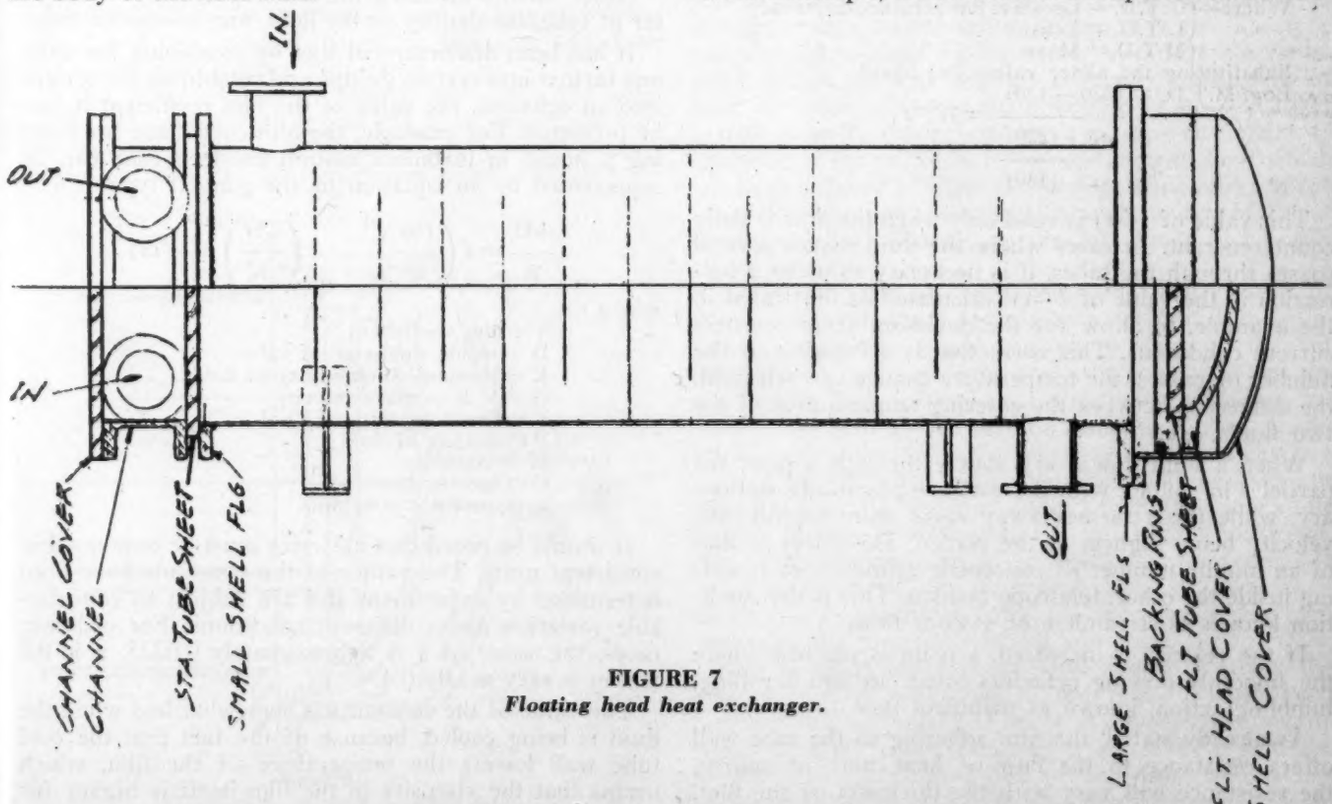


FIGURE 7
Floating head heat exchanger.

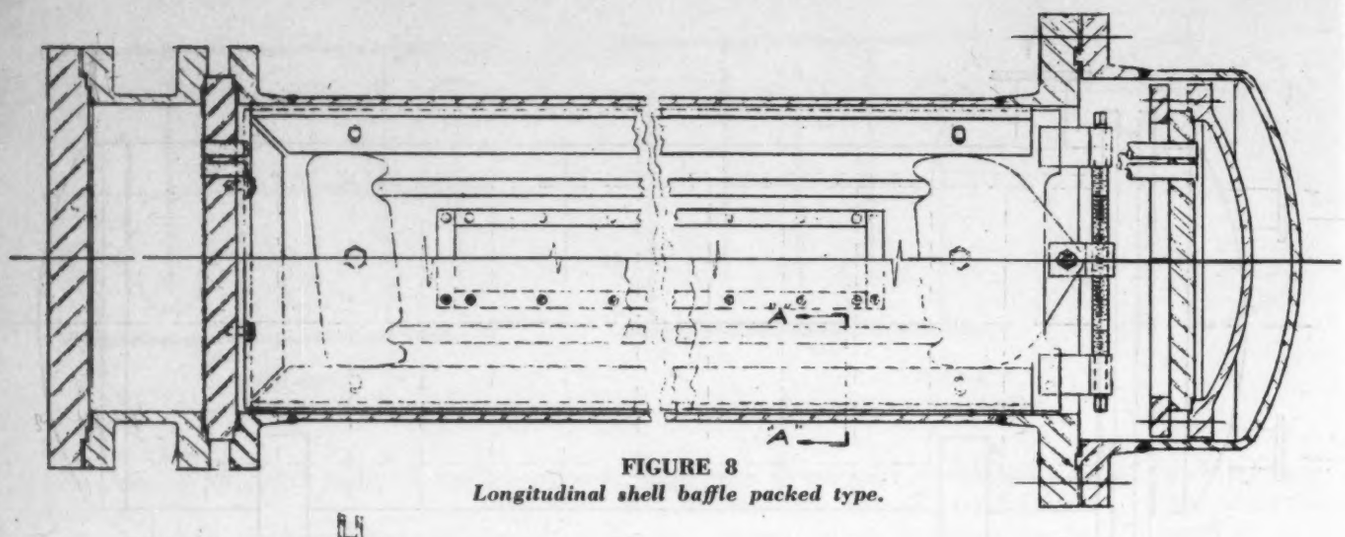
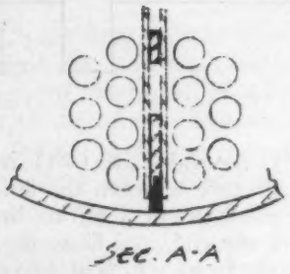


FIGURE 8
Longitudinal shell baffle packed type.



the fluids varies from 130°F. at one end to 220°F. at the opposite end. The question arises, therefore, as to the correct value of (Δt) for use in equation (3). It has been shown that in such cases, the correct value is the logarithmic mean of the differences at the ends of the exchanger. This is calculated as follows:

$$\text{Log. M.T.D.} = \frac{(\text{C.T.D} - \text{L.T.D.})}{\log. e \dfrac{(\text{G.T.D.})}{(\text{L.T.D.})}}$$

Where—(G.T.D. = Greatest temperature difference
(L.T.D. = Least " "
(M.T.D. = Mean " "

Substituting the above values, we have:

$$\text{Log. M.T.D.} = \frac{(220 - 130)}{\log. e \dfrac{(220)}{(130)}} = 171°\text{F.}$$

This value of (Δt) is valid only when the flow is truly countercurrent. In cases where the fluid makes several passes through the tubes, it is necessary to make a correction in the value of (Δt), calculated as illustrated in the example, to allow for the deviation from countercurrent conditions. This correction is a function of the number of passes, the temperature change of each fluid, the difference between the entering temperatures of the two fluids, etc.

When a fluid flows very slowly through a pipe, the particles in contact with the wall are practically stationary, while those farther away move more rapidly, the velocity being highest at the center. The effect is that of an infinite number of concentric cylinders, each sliding inside the other, telescope fashion. This is the condition known as streamline or viscous flow.

If the velocity is increased, a point is reached where the smoothly flowing cylinders break up into a rolling, tumbling action, known as turbulent flow.

As already stated, the film adhering to the tube wall offers resistance to the flow of heat, and, of course, the resistance will vary with the thickness of the film.

The two main factors affecting the film thickness are the velocity of the fluid, and its viscosity. It is quite evident that increased velocity will decrease the thickness of the film, and, of course, turbulent flow results in a much thinner film, and correspondingly higher heat transfer coefficient, than streamline flow.

Since viscosity is the measure of the internal friction of a fluid, or its resistance to flow, it has a very important effect on the film thickness. It also plays an important part in controlling the point at which the flow changes from streamline to turbulent, so that an increase in viscosity lowers the heat transfer rate.

The rate of heat flow, or film coefficient is governed not only by the thickness of the film, but also on the thermal conductivity of the fluid forming the film. This is a very important factor, since the film is practically stationary, and the heat must flow through as it would flow through a layer of insulation.

Other factors affecting the film coefficient are diameter of tube, the density of the fluid, and its specific heat.

It has been demonstrated that by combining the various factors into certain groups and combining the groups into an equation, the value of the film coefficient h, can be predicted. For example, the film coefficient for heating a liquid in turbulent motion inside a tube can be represented by an equation of the general type

$$\frac{hD}{K} = a\left(\frac{DG}{M}\right)^n \left(\frac{CM}{K}\right)^m \qquad (4)$$

where

h = film coefficient
D = inside diameter of tube
K = thermal conductivity of fluid
G = V P = mass velocity
V = lineal velocity of fluid
P = density of fluid
M = viscosity
C = specific heat
a, m, and n = constants.

It should be noted that all terms must be expressed in consistent units. The values of the constants have been determined by experiment and are subject to considerable variation under different conditions. For ordinary cases, the value of a is approximately 0.0225, n is 0.8 and m is very nearly 0.4.

The value of the constants is somewhat less when the fluid is being cooled, because of the fact that the cold tube wall lowers the temperature of the film, which means that the viscosity in the film itself is higher for

cooling than for heating. The value of n decreases with the lower values of DG/μ. Also, as the value of DG/μ is reduced, the accuracy of the equation is decreased until the point is reached where the flow becomes streamline, when it fails entirely, and a different type of equation is necessary.

The calculation of the film coefficient in the shell space on the outside of the tubes is complicated by the necessity of evaluating a shape factor or equivalent diameter, which depends on the shell diameter, the number, diameter and arrangement of the tubes, also, the number, type, and arrangement of the shell baffles. No attempt will be made to go into detail, as this is too complicated to discuss at this time.

After calculating the film coefficients on the inside and outside, of the tubes, the overall coefficient is obtained by combining their reciprocates with that of the tube wall itself as follows:

$$U = \frac{1}{\frac{1}{h_t} + \frac{1}{h_w} + \frac{1}{h_s}} \qquad (5)$$

where

U = overall coefficient
h_t = film coefficient inside the tubes
h_w = rate of heat flow through the tube wall
h_s = film coefficient outside the tubes.

The discussion up to this point has been dealing mainly with liquid-to-liquid heat exchangers. There are, of course, many other types of heat transfer apparatus, such as condensers, reboilers, etc., operating under widely varying conditions, each requiring special treatment. For example, in a condenser, the heat transfer coefficient must be figured for cooling the vapor, condensing the vapor and cooling the condensate. The problem may be further complicated by the presence of steam and non-condensible gas, each of which has an important effect on the overall heat transfer coefficient.

The heat load, or duty, the mean temperature difference, heat transfer coefficient and surface must be calculated separately for condensing and cooling each component and the surfaces figured in this way added, to obtain the total surface required.

It can be seen, therefore, that in such cases, the overall M.T.D. and overall coefficient have very little significance.

In calculating the film coefficient inside the tubes, it

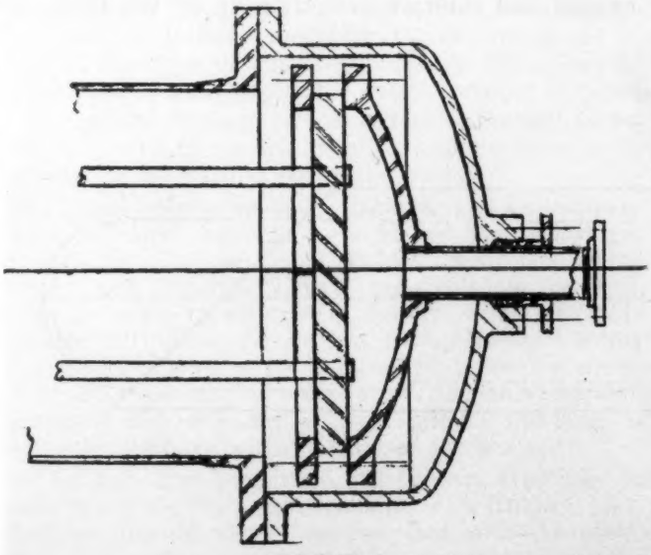


FIGURE 9
Floating head with stuffing box.

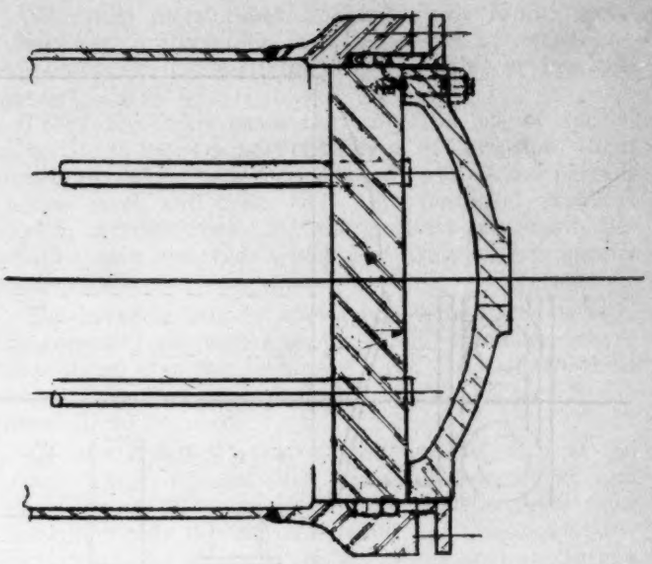


FIGURE 10
Outside packed floating head.

should be noted that the coefficient applies to the actual film area, which is equal to the inside surface of the tube. Since it is customary to specify the size of an exchanger on the basis of outside tube surface, the film coefficient calculated for the inside of the tubes must be corrected to allow for this difference.

While higher velocities increase the heat transfer coefficient they also increase the friction or pressure drop through the unit. It is of great importance, therefore, that the refiner specify the maximum pressure loss which he can allow without inconvenience, since this definitely controls the heat transfer coefficient, thereby controlling the size of the exchanger.

As every refiner knows, the efficiency of an exchanger varies with the length of time which has elapsed since it was cleaned. This is caused by the accumulation of foreign matter on the tubes, known as scale. The type and amount of scale varies widely in different installations, but in any case it offers resistance to the flow of heat. In order to assure the operation of an exchanger at full capacity throughout the run, it is customary to construct it on the basis of an overall coefficient which has been reduced to allow for the insulating effect of the scale. This is sometimes done by multiplying the calculated overall coefficient, or the individual film coefficients by a factor.

Since the scale is a resistance, the heat instead of passing through three resistances as indicated in equation (3) actually passes through 5, namely, the hot film, the hot scale, the tube wall, the cold scale and the cold film. The preferable method of correcting for scale, therefore, is to include scale or fouling coefficients in equation (3). To illustrate this, consider two exchangers operating under identical conditions, except that the velocity in one is higher than the other. The higher velocity, of course, results in a higher coefficient. The resistance of the scale formation, however, is numerically the same in either case, so that when figured on a percentage basis, the reduction in the efficiency of the two units is not the same.

It frequently happens that the refiner specifies the desired fouling coefficient in the inquiry when such information is available. This is of considerable importance, since the scale resistance is primarily a function of the chemical composition of the fluid, and is not apparent from the characteristics usually specified in an

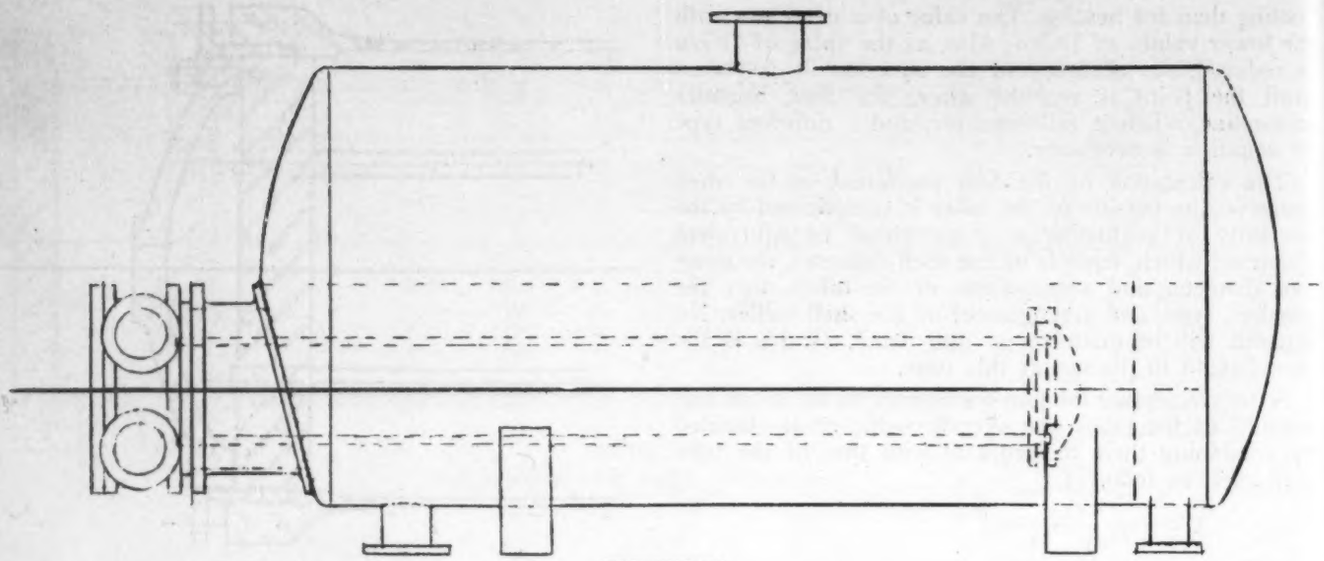


FIGURE 11
Storage type vaporizer or reboiler.

inquiry. This, also, allows all manufacturers to compete on an even basis.

No attempt has been made to present the subject of heat transfer in sufficient detail to enable an inexperienced person to properly design heat exchangers. Such problems really require the services of a specialist, and most refiners are glad to leave this to the manufacturer, who has made a thorough study of such work. It is unfortunate, however, that the equipment is usually purchased from the manufacturer who will meet the specified operating conditions at the lowest price. Due to the very keen competition among the various manufacturers, it is necessary to utilize every possible method of lowering the cost of the unit. While this has been a great stimulation to the manufacturers in developing highly efficient equipment at a very low price, it frequently means the installation of equipment which becomes a source of trouble for the operating department, and more expensive in the long run, even though it meets the specified conditions at a low first cost.

One of the most common methods of reducing the cost of an exchanger is the use of long tubes having a small diameter. In addition to the fact that such tubes produce a higher heat transfer coefficient, so that less surface is required, they, also, allow the use of a smaller shell for a given amount of tube surface, with a correspondingly lower price. The greater the length and the smaller the diameter of the tubes, the more difficult they are to clean. While such tubes are satisfactory in certain cases, most refinery exchangers should have tubes large enough and short enough to allow them to be cleaned easily. There is a growing tendency toward the use of tubing having a minimum outside diameter of 1 inch, and a maximum length of from 8 to 10 feet for units installed at any considerable elevation about the ground and 12 to 16 feet for units installed within easy reach. Many refiners purchase tubes for replacement in large quantities, in which case it is desirable to have all tubes in the refinery of one size, gauge and length.

Many exchangers have been built with the tube sheets permanently attached to the shell, and while in some cases this is permissible, floating head construction is preferable in a very great majority of instances, and is frequently an absolute necessity. The floating head serves two important purposes. It allows the tubes to expand and contract independently of the shell, and

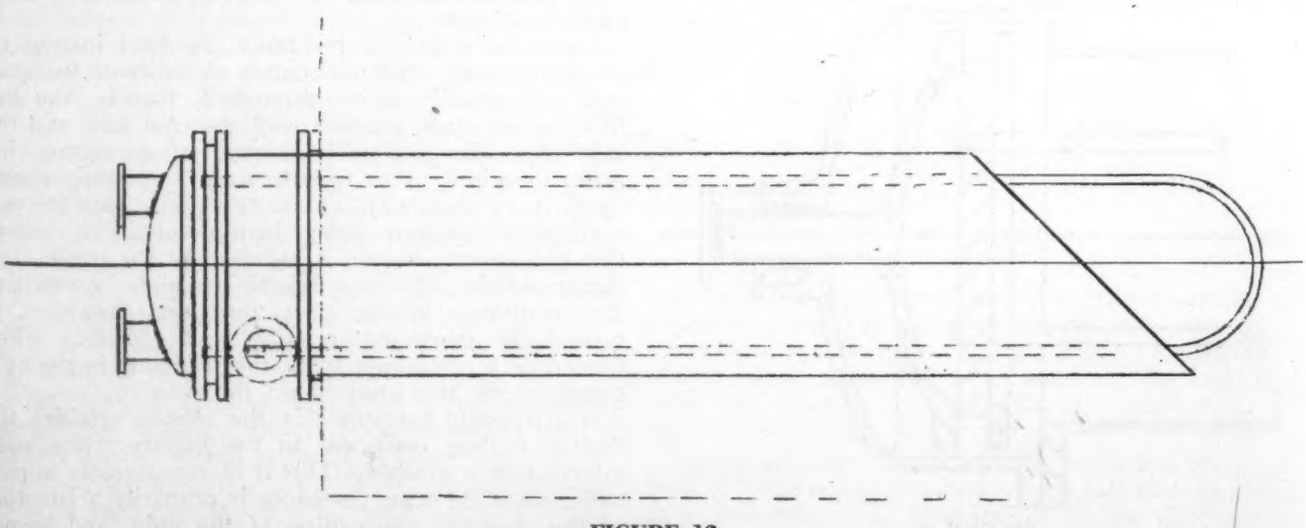


FIGURE 12
Tank suction heater.

permits the tube bundle to be removed for inspection, cleaning and tube replacement.

Most exchangers are so constructed that the center of each tube forms the apex of an equilateral triangle, and is referred to as triangular, or diamond pitch. The spacing of the tubes has in the past been subject to rather wide variation, but has been fairly well standardized during the past two or three years. The most common center-to-center distances are 13/16 inch, 61/64 inch, 1¼ inch and 1½ inch, for ⅝ inch, ¾ inch, 1 inch and 1¼ inch tubes respectively. While these dimensions have been proven satisfactory, they should be considered as the minimum dimensions permissible, since closer spacing weakens the tube sheet beyond the danger point, and causes excessive warping, when the tubes are rolled in place.

This tube arrangement is the most compact and economical, and is entirely satisfactory when operated with comparatively non-scaling fluids in the shell, or when the scale can be removed by the action of a solvent. Such a bundle does not, however, allow access to its interior. In cases which require mechanical means for the removal of scale, the bundle should be provided with so-called "cleaning lanes." This is accomplished by using a greater pitch, or by arranging the square. In either case, clear openings are provided, which extend entirely through the bundle, and permit a cleaner to be inserted.

The gauge of the tubes has some bearing on the cost of an exchanger, and when this is not specified, the manufacturer is forced to use the minimum gauge which will stand the existing pressure. This frequently means a short tube life, while a comparatively small increase in first cost would allow the use of heavier tube walls, and very materially increase the life of the tube bundle.

One of the most common sources of trouble in the operation of heat exchangers is leakage at the point where the tubes are expanded into the tube sheet. While all reputable manufacturers use roller expanders for this operation, it is difficult to assure a leakproof job when tubes are expanded into plain drilled holes. It has been found, however, that by cutting two parallel grooves in the tube hole, leaks may be eliminated almost entirely, and the tube itself will fail before it pulls out of the tube sheet. While most manufacturers have adopted this construction as standard for severe temperature or pressure conditions, they cannot afford it on the highly competitive, low-pressure, low-temperature jobs. It is well, therefore, for the purchaser to specify this type of construction, since the saving in maintenance cost justifies the small increase in price.

In case the fluids to be handled are especially corrosive, it is well to specify the additional thickness to be allowed on the various parts, for corrosion.

Carbon steel is the most common, and in ordinary cases the most desirable material for heat exchanger construction. The use of butt-welded shell joints having forged steel, hub-type flanges butt welded to the shell, with all joints radiographed, and the whole assembly annealed to relieve the stresses set up by the welding arc, results in what is for practical purposes, the equivalent of a seamless one-piece job. While such excellent quality is not necessary in a great many instances, it is highly desirable when conditions are severe.

Cast iron has been used extensively, especially in cases where slightly corrective fluids were handled, however, because of recent improvements in safety standards, it is seldom used at present except for water or steam at low temperature and pressure.

Admiralty metal tubes, and bronze or Muntz metal tube sheets are common in certain types of exchanger, especially when one of the fluids is salty or brackish water.

There are many cases requiring the use of special materials to resist a particular type of corrosion. Ingot iron is useful on some occasions, as well as 4-6 percent chrome steel, and even 18-8 Chrome-nickel stainless steel in extreme cases. Metallurgists are continually developing new materials which find usefulness in special applications.

The operator usually knows better than anyone else, the corrosive properties of the fluids which he desires to process, and the materials most resistant to their action. It is, therefore, desirable for him to specify the materials to be used.

There are many types of shell baffles, such as the orifice type, ring and disc, cross flow or spiral, and can safely be left entirely to the manufacturer, since they affect only the thermodynamic performance of the exchanger, and this, of course, is the manufacturer's responsibility. In cases requiring cleaning lanes, it is well to maintain a minimum baffle spacing of 3 inches or possibly 4 inches. In other cases, construction difficulties, cost and pressure drop are the limiting factors.

Two-pass shells have been more or less unsatisfactory in the past because of the leakage between the shell and the baffle. Recently, however, baffles have been developed which form a positive seal at this point, and are at the same time, easily removed with the tube bundle. It is well for the purchaser to require that any two-pass shell be provided with such a seal, when used in a heat exchanger handling liquids. This is not so important in the case of vapor exchangers or condensers, since the leakage in such cases is small in proportion to the total volume of vapor.

Generally speaking, one large exchanger is lower in cost than two small ones for the same service. This does not hold true in the case of high-pressure units, since the excessively heavy construction necessary for the large diameter results in excessive cost. The size of the individual exchanger section is also limited by the difficulties in handling.

Frequently, the length of time a cracking or distillation unit can be kept on stream is limited by the fouling of a heat exchanger. In such cases, it is advantageous to have the exchanger constructed in multiple sections and arranged so that any one may be by-passed and cleaned, while the remaining sections continue to carry the full load.

While it has been necessary to confine this discussion to general considerations only, it is hoped that it will give the purchasers and operators of heat exchangers, especially the refiners who do not maintain a large engineering department, a better understanding of the problems involved.

While, as stated before, many of the difficulties arising in the operation of heat exchangers have been due to the efforts of the manufacturer to reduce the price, a great deal of the responsibility rests on the purchaser, for failing to specify the various features necessary for first-class construction. This does not indicate a lack of cooperation on the part of the purchaser, but it does mean that many persons responsible for the operation of such equipment have not had a clear understanding of the problems confronting the designer.

The experiences of the operator with various types of construction are of utmost importance to the manufacturer, who is responsible for the design of the equip-

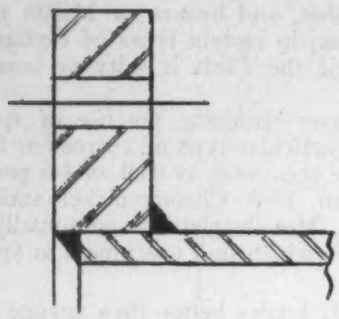


FIGURE 13

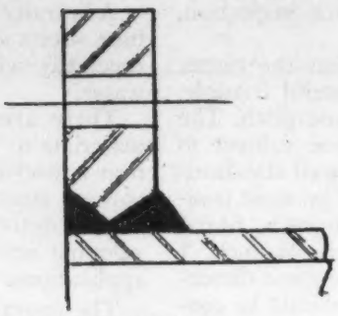


FIGURE 14

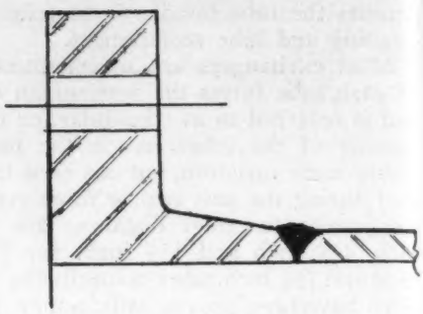


FIGURE 15

Shell flanges.

ment. In the final analysis, the purpose of a heat exchanger is to transfer a given amount of heat from one fluid to another, in the manner most economical and satisfactory to the operator. The maufacturer is more than anxious to do his part in accomplishing this result, and the operator can be of very great assistance by noting the features which he finds desirable, and passing such information on to the manufacturer.

TYPES OF HEAT EXCHANGERS

In order to clarify certain points in regard to the construction of heat exchangers, the different types and the various construction features will be briefly described.

The simplest form of heat exchanger is illustrated in Figure 1. It consists of a shell, welded directly to the tube sheets, into which the tubes are rolled. The head flanges are bolted to the tube sheets, and one fluid flows in a single pass through the tubes, while the other flows in the opposite direction through the shell. This is an illustration of true countercurrent flow.

The shell baffles may be ring and disc type (Figure 2), cross flow (Figure 3) or orifice type (Figure 4).

In Figure 2, the fluid flows from the shell toward the center of the exchanger, through the opening in the ring baffle, then toward the shell around the edge of the disc baffle, and back toward the center. This type is useful only when the quantity of fluid is very large.

In Figure 3, the baffles are circular, except that a segment is cut from one side, and the cuts placed alternately on one side of the shell and then the other, so that the fluid must flow back and forth across the tube bundle. This is probably the most common type of baffling.

The baffles illustrated in Figures 2 and 3 are made to fit as tightly as possible around the tubes, to prevent leakage and loss of efficiency.

In Figure 4, the baffles are circular, and have the tube holes drilled 1/32 or 1/16 inch larger than the tubes, so that the entire quantity of fluid is forced to flow at high velocity through the annular openings around the tubes. This type of baffle is widely used, especially when the quantity of fluid is too small to give a good velocity in the cross flow type.

Figure 1 may be modified by placing baffles in the heads, and both inlet and outlet connections at one end, so that the fluid makes two or more passes through the tubes. This requires that a correction be applied to the

FIGURE 16

Raised face gasket joints.

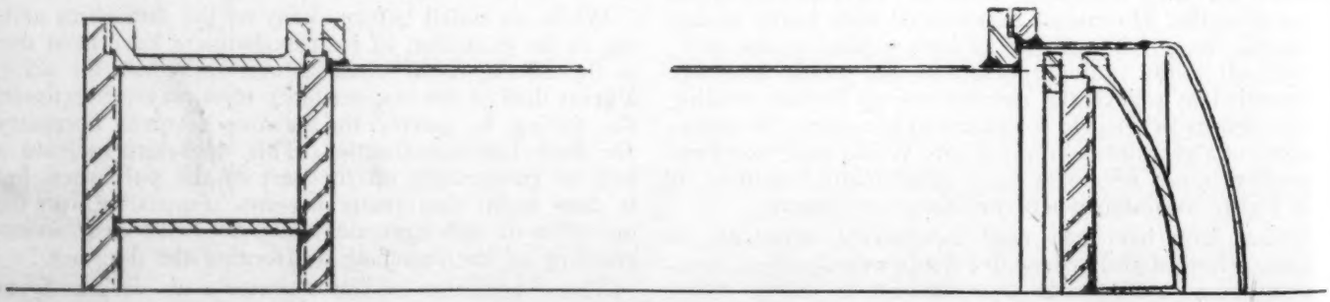


FIGURE 17

Confined type gasket joints.

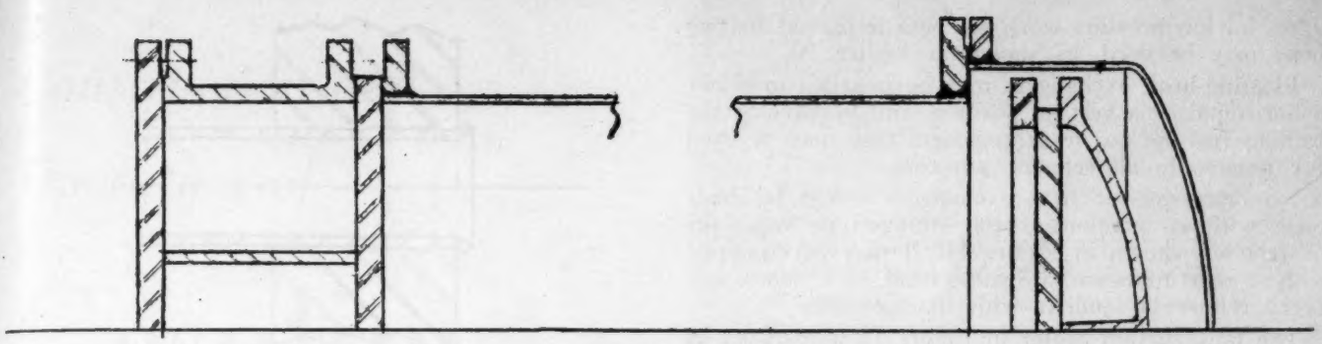


FIGURE 18
Fully confined type gasket joint.

log. mean temperature difference, but the higher heat transfer coefficient resulting from the increased velocity usually more than compensates for the M.T.D. correction.

Occasionally it is found desirable to install a longitudinal baffle, and place both shell nozzles at one end, making a two-pass shell. In case the diameter of the shell will not permit a workman to enter for the purpose of welding the baffle to the shell on the inside, it is well to split the shell at the center, and weld the halves together, at the same time welding the baffle in place, as illustrated in Figure 5.

It is very important to remember that the type of construction illustrated in Figure 1, is very limited in its application, and is never recommended except for low temperatures, and low shell pressures, in cases where the shell fluid is non-scaling. It is doubtful that it should ever be used for temperatures above 200°F., or with a shell pressure above 150 pounds gauge, although they have been operated successfully at 300 pounds gauge on certain occasions.

Figure 6 illustrates the "U" tube heat exchanger. The shell is provided with a bolting flange at one end and a dished head welded to the opposite end. The tubes are "hairpin" shape, rolled into the single tube sheet, so that no stresses are produced as a result of expansion, and the tube bundle is removable for cleaning or inspection.

Figure 7 illustrates what is by far the most important type of heat exchanger construction, since, with minor variations, it represents probably 80-90 percent of the heat exchangers in use in the oil refining industry.

The tubes are longer than the shell, one end being rolled into the stationary tube sheet, which is clamped between the small shell flange and the channel flange. At the other end the tubes are rolled into the floating-tube sheet, which is provided with a cap, or floating-head cover. The fluid flows from the channel through a group of tubes to the floating-head cover directing it back toward the channel end through another group.

The floating-tube sheet is very slightly smaller than the inside diameter of the shell, so that it may be withdrawn through the shell. The floating-head cover is larger than the tube sheet, and is clamped against it by means of the split backing ring. There are many variations in construction details of the floating head, but since the fundamental principle is the same, they need not be considered at this time. The shell cover, or bonnet is large enough to enclose the complete floating-head assembly.

This type of construction allows the free expansion of the tubes, independently of the shell, allows the removal of the tube bundle for cleaning or inspection, and since the tube bundle almost entirely fills the shell the efficiency is high and the cost low, since a smaller shell can be used for a stated amount of tube surface than would be possible without this feature. Furthermore, the heads can be removed, and the tubes inspected or cleaned without breaking any pipe connections.

The same types of shell baffling are used as illustrated in Fgures 2, 3 and 4. In cases where a longitudinal baffle is used, it must be removable with the tube bundle. It is, therefore, necessary to provide some sort of seal between baffle and shell to prevent leakage and loss of efficiency. Many methods have been tried but very few were satisfactory. What is believed to be the most satisfactory seal yet constructed is illustrated in Figure 8. The baffle consists of two plates, provided with woven asbestos packing at each side, which is impregnated with a special oil-resisting cement. The packing is compressed against the shell by means of a screw and cam arrangement, forming an excellent seal.

When a floating-head exchanger is required with a single pass through the tubes, it is necessary to provide a stuffing box at the point where the outlet connection passes through the shell cover as illustrated in Figure

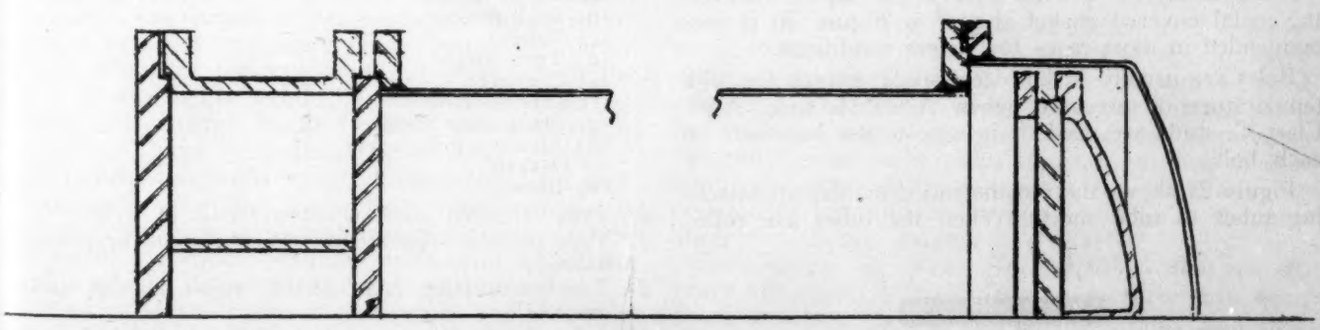


FIGURE 19
Full tongue and groove type gasket joint.

9, or, for low pressure work, the outside packed floating head may be used, as shown in Figure 10.

Floating-head exchangers may be installed in either a horizontal or a vertical position, and by varying the baffling and the nozzle arrangement they may be used for practically all refinery purposes.

No discussion of heat exchangers would be complete without mention of the storage-type vaporizer or reboiler, shown in Figure 11. It may be equipped with straight tubes and a floating head, or U-tubes, and every refiner is familiar with its operation.

The tank suction heater in Figure 12 is installed in the storage tank for the purpose of heating viscous oils to a temperature at which they can be pumped.

There are, of course, other types of heat exchangers, but those already described will probably serve the present purpose.

CONSTRUCTION DETAILS

Figure 13 shows the simplest method of welding the flange to the shell. While this has been used for many years with entirely satisfactory results, it is now being displaced by the methods shown in Figure 14 and 15, which are approved by the API-ASME Code, especially on high-pressure, high-temperature work. The forged steel, high-hub flange, but welded to the shell as shown in Figure 15, is obviously the most desirable construction, and usually justifies the small additional cost. If the conditions are at all severe, it is wise to have the joints radiographed and stress-relieved.

Figure 16 shows the raised face type of gasket joint. This is satisfactory in many low-pressure, low-temperature exchangers, especially when handling water or steam.

Figure 17 illustrates an improved joint which provides a shoulder on the outside of each gasket to hold it in place.

Figure 18 shows a type of construction providing a double shoulder effect, so that the gasket is confined on both inside and outside.

Figure 19 shows the full tongue and groove type joint construction. There is very little choice between Figures 18 and 19, except that Figure 18 is more economical of shell space and permits the use of a few extra tubes, which is important in many cases.

Figure 17 is economical in cost, and is recommended as entirely satisfactory in a majority of instances.

Gaskets may be cut from sheets of asbestos composition, which may be obtained in various grades, suitable for a wide range of temperatures, or may be built up of a metal cover with an asbestos insert as shown in Figure 20.

Occasionally solid metal gaskets are used; however, the metal covered gasket shown in Figure 20 is recommended in most cases for severe conditions.

Bolts are usually carbon-steel studs, except for high temperature or pressure, when A.S.T.M. spec. A-96, Class C, studs are used. It is wise to use two nuts on each bolt.

Figure 21 shows the recommended manner of attaching tubes to tube sheets. When the tubes are rolled into the grooves shown, a very strong joint results, and leaks are very unusual.

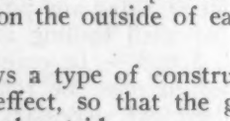


FIGURE 20
Metal covered asbestos gasket.

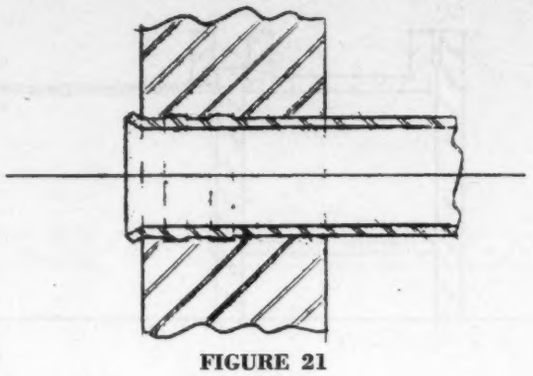


FIGURE 21
Tube Joint.

HEAT EXCHANGER SPECIFICATIONS

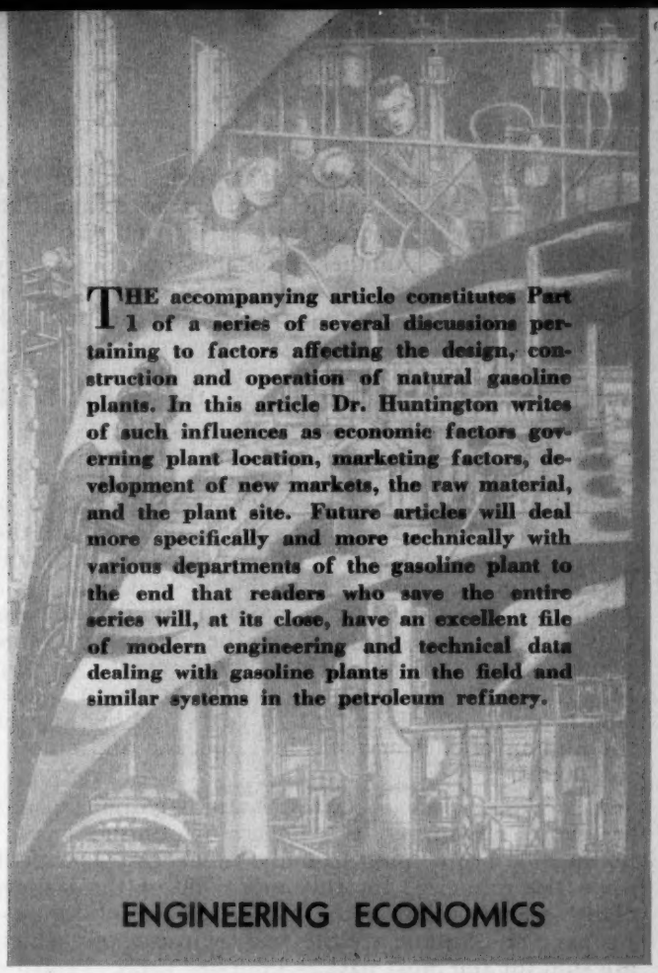
To assist the purchaser in preparing specifications, a list of desirable information is submitted. It is understood, of course, that all such information will not be available in all cases. As much of this should be supplied as possible, however, otherwise it will be necessary for the designer to make assumptions which may or may not be correct.

1. Character of fluid.
2. Quantity of fluid.
3. Gravity of fluid.
4. Viscosity (at two temperatures).
5. Inlet temperature.
6. Outlet temperature.
   NOTE: In the case of cooling water, specify either the outlet temperature, or the quantity. It is not necessary to specify both.
7. Quantity condensed.
8. Quantity vaporized.
9. Distillation characteristics if vaporization or condensation occurs (A.S.T.M or true boiling point).
10. Operating pressure.
11. Maximum working pressure.
12. Maximum allowable pressure drop.
    NOTE: The above information (1-12 inclusive) should be supplied for both hot and cold fluids.
13. Which fluid in tubes?
14. Fouling factor, or scale coefficient (optional).
15. B.S. & W. content of fluids.
16. Extra thickness to be allowed for corrosion.
17. Outside diameter, gauge and maximum length of tubes.
18. Arrangement of tubes (diamond or square pitch) and minimum center to center distance.
19. Number of sections (shells) (optional).
20. Is spare section required (for cleaning while on stream)?
21. Materials of construction
    (a) Shell
    (b) Shell flanges
    (c) Tubes
    (d) Tube sheets
    (e) Channel
    (f) Channel cover
    (g) Shell cover (bonnet)
    (h) Floating head cover
    (j) Gaskets
    (k) Bolts.
22. Type of gasket joints (Figures 16, 17, 18 or 19).
23. Type of tube joint at tube sheet (smooth or grooved holes).
24. Type of welding (API-ASME, stress-relieved, radiographed).
25. Any special information of whatever nature which might affect the design or construction of the exchanger.
26. Point of delivery.

Construction and Operation of

Gasoline Plants

R. L. HUNTINGTON
University of Oklahoma



THE accompanying article constitutes Part 1 of a series of several discussions pertaining to factors affecting the design, construction and operation of natural gasoline plants. In this article Dr. Huntington writes of such influences as economic factors governing plant location, marketing factors, development of new markets, the raw material, and the plant site. Future articles will deal more specifically and more technically with various departments of the gasoline plant to the end that readers who save the entire series will, at its close, have an excellent file of modern engineering and technical data dealing with gasoline plants in the field and similar systems in the petroleum refinery.

ENGINEERING ECONOMICS

THE natural gasoline industry had its beginning in "casinghead" gasoline plants which started operating in western Pennsylvania and West Virginia about 30 years ago. The term "casinghead" was first used because the gasoline was extracted from the gas produced through the casing-heads of oil wells which had long ceased to flow naturally. The gas from these pumping wells was so rich in gasoline content that some condensate formed, without compression, in cold weather in the low-pressure fuel gas lines leading from the wells.

The first method of extracting these volatile gasoline condensates from the gas was that of single-stage compression followed by cooling. This method soon developed into the well-known two-stage compression process. Since then the compression method has been largely replaced by the oil-absorption process, except in a few fields where the gas contains from 5 to 10 gallons or more of gasoline per 1,000 standard cubic feet of gas.

With the discovery of large fields in the Mid-continent area early in the present century, it was found that in addition to casinghead gas, much larger volumes of gas could be profitably processed from the flowing wells which produced their oil and gas into flow tanks and separators. To include the gas from these flowing wells the industry saw fit to change the name of "casinghead" to "natural" gasoline in order to convey more clearly the nature of the source of the raw material from which the gasoline was being produced. Another reason for making this change in the name of the industry is the fact that large quantities of gasoline are produced from natural-gas wells which are not equipped with casingheads. The gas from these wells usually is processed through a high pressure booster station and an oil-absorption gasoline plant, after which the residue gas is delivered as fuel to cities and industries. The chief source of revenue for plants of this type comes from the sale of gas as fuel. Although natural gasoline is considered a by-product, its recovery is generally a source of profit. If not extracted the gasoline condenses in the lines and is blown out through drips, and wasted. If the gasoline is allowed to condense in the lines it causes the gaskets on sleeve couplings to dissolve or deteriorate, resulting in many gas leaks. The gasoline content of most natural-gas wells runs from 0.25 to 0.40 gallons per thousand cubic feet.

With the development of various cracking processes in the refining industry there has been a rapid increase in the production of natural gasoline from cracked gases. This factor has slowed down the rate of growth of the branch of the natural gasoline industry which makes gasoline from gas produced in oil fields. The new developments in polymerization processes may tend to reduce the yield of natural gasoline made in connection with the cracking process, since a large portion of the unsaturated hydrocarbon gases which are now recovered as natural gasoline will be polymerized into larger molecules having a volatility comparable to ordinary motor fuel.

MARKETING FACTORS

So far as the market of natural gasoline is concerned, the industry may be classified as a complementary one. By this is meant that the industry sells a large fraction of its output as a semi-finished product to the refiner who blends the natural gasoline with less volatile petroleum fractions to produce finished motor fuels. The natural gasoline manufacturer is also dependent upon the oil producing division of the industry in that he looks to the producer for his raw material.

Development of New Markets. For the past 10 years the natural gasoline manufacturer has been doing his best to develop new products and new markets so that he will not be entirely dependent upon the refiner for his market. Wherever it is possible the natural gasoline plant is located so that the

dry residue gas can be sold as fuel. In fact, the value of the dry gas as fuel is often more than that of the gasoline recovered from fairly rich gas.

Carbon Black. Another profitable outlet for dry gas has resulted from the rapid growth of the carbon black industry. About 70 percent of the carbon black is used in the manufacture of automobile tires, and the other 30 percent in the making of inks and paints. While the price obtainable from the carbon black plants is much lower than it is from the gas companies as fuel, the large quantities required for carbon black, bring many thousands of dollars profit annually to the gasoline manufacturer. This is especially true in the Texas Panhandle where the carbon black plants have concentrated, on account of the large gas reserve available in that area. The likelihood also of selling a major portion of the excess residue gas as fuel from the natural gasoline plants in that extensive field, is quite remote. Carbon black plants were forced to leave the northern Louisiana fields to a large extent 10 years ago because of the finding of fuel markets in Louisiana and adjoining states.

Liquefied Petroleum Gases. Natural gasoline plants are now producing a number of finished products which are helping to make them less dependent upon the refineries for revenue. One of the largest of these new outlets is the market for liquefid gases. Propane and butane are the two hydrocarbons which are sold for the most part as liquefied fuels. Propane was considered a drug on the market until it was found that it makes an ideal fuel for domestic cooking and heating, wherever manufactured or natural gas is not available. Since the natural gasoline used for blending requires only a certain amount of butane to give it necessary volatility, the finding of a market for excess quantities of butane has been a big help to the natural gasoline industry. Butane can be liquefied and shipped at much lower pressures than propane. Butane is particularly adaptable as a fuel which can be carbureted with air and distributed to small towns at a much lower cost than that of manufacturing and distributing producer or water gas. Butane has also proven to be an ideal carburizing agent in the manufacturing of various steels.

Aviation Fuels and Solvents. By debutanizing natural gasoline, aviation motor fuels are being manufactured and sold directly as a finished product not only for airplanes, but also for winter motor fuels in the northern part of the United States and in Canada. Several of the larger companies have developed markets for special solvents prepared through the fractionating of pentane, hexane and heptane fractions. Although this market is small compared to the liquefied gas and aviation fuel markets, it is growing in size and is helping to make the natural gasoline manufacturer more independent as the result of the diversification of his products. High-pressure stabilization has made it possible for the natural gasoline plants to produce these various finished products.

THE RAW MATERIAL

(1) *Location of center of oil and gas producing area.* This part of the discussion will be limited to those natural-gasoline plants which manufacture natural gasoline from oil-producing, and natural-gas wells. It is the general rule that all manufacturing plants try to locate as near as possible to their markets. This rule applies to gasoline plants, but it is not as vital since it is entirely out of the question to attempt to transport the raw product, gas, over a long distance before it is processed in the plant. The main factor therefore is to locate the plant as near the center of the gas producing area as possible. It is quite easy to determine the center of this area in a proven field; however, many gasoline plants are forced to start building programs when the field is in its infancy. This was especially true, between 1920 and 1930 when highly competitive conditions forced the companies to contract for the processing of the gas shortly after each well was completed. The gasoline manufacturer often had to choose between the alternative of handling the gas within a short time after the wells were brought in or pay for the gas which was not processed after a certain contractual time limit had expired. The only method of arriving at the approximate center of the gas production in such new fields is that of making a geological survey in advance of the drilling program. This step is indeed a hazardous one because the extent of deep structures is more difficult to ascertain than the shallower ones, but it is the only one to take if the gasoline manufacturer expects to obtain its share of the gas. Fortunately such highly competitive races for gas have not been so keen since 1930. Then, too, the oil companies have realized that it does not pay to go into a natural gasoline situation unless most of the gas in the particular area can be processed. The gradual decline in the price of natural gasoline has forced many of the smaller plants to sell out to the larger ones. A number of companies have gone so far as to trade gas in different fields and in different parts of the same field so as to save the cost of building new plants or laying additional gas-gathering lines. In many fields the overlapping of pipe lines by different companies has resulted in the expenditure of many thousands of dollars which could have been avoided through the exchange of gas contracts.

(2) *Exploration or Reconnaissance Work.* The quantity and quality of the gas from the field can best be ascertained by sending a test car to the particular field. The gas volumes from flowing wells usually are obtained by open flow or Pitot tube measurements.[3] If the volume from a well is less than 200 thousand cubic feet per day, an orifice well tester may be used. Such small volumes however are rarely found except in old producing fields where the wells are being pumped. Proration restrictions on many new fields often prevent the obtaining of gas volumes, representative of the maximum producing capacities of the wells. In such cases a study of the physical state of the underground reservoir[1,2] is desirable. Such studies include not only calculations of the amount of gas originally present in a reservoir but also the quantity of crude oil. The ratio of available natural gasoline to crude oil production can also be estimated by knowing the composition of the original bottom fluid (including liquid and gas) and by predicting the future oil-producing methods to be used in the field. For example, if gas-lift is expected to take a big part in the oil production program, the overall gas-oil ratio usually will run high, and the gasoline content relatively low, but the ratio of natural-gasoline production to that of crude oil will generally be much higher than it would if the wells were produced by some pumping method.

The gasoline content of the gas may be determined either by charcoal absorption or by the compression

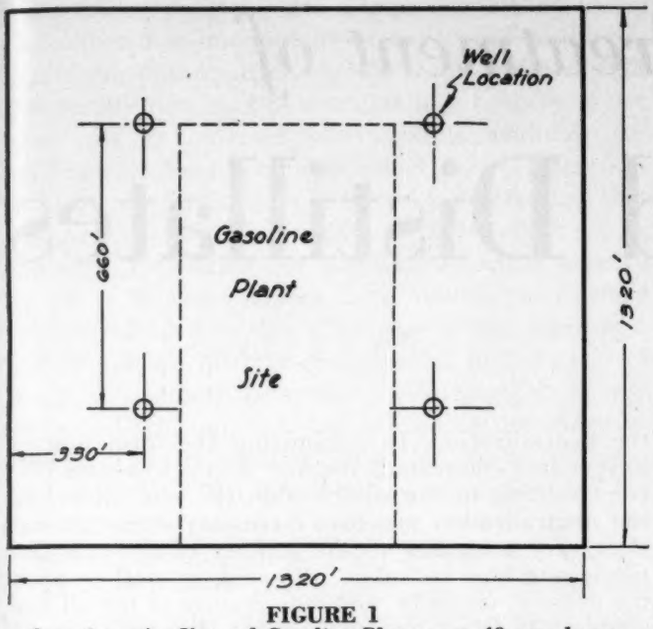


FIGURE 1
Location of a Natural Gasoline Plant on a 40-acre lease.

test. Although the oil-absorption method is used in the actual production of natural gasoline, the oil-absorption test is seldom used in field testing on account of the bulkiness of the apparatus and the greater length of time required for making the test. The charcoal test is particularly adapted for gas containing less than a gallon of gasoline per 1000 cubic feet while the compression test gives better results for richer gas. The charcoal test requires less investment in field apparatus, as the saturated samples of charcoal can be transported to a central laboratory for distillation. If the gas contains less than one half-gallon per thousand cubic feet the compression test is apt to show only a fraction of the true gasoline content. In addition to the field test, several representative gas samples from over the district should be shipped to a central laboratory for complete analysis. Such would include true boiling point distillations to determine the percentages of each constituent in the gas, tests for sulphur compounds, and test for inert gases like carbon dioxide, nitrogen, helium, etc. The presence of hydrogen sulphide above one percent by volume in a gas causes a marked increase in manufacturing cost due to the corrosion of equipment and to the expense of treating the gasoline and fuel gas.

THE PLANT SITE

Once the approximate center of the gas area has been determined the selection of the plant site should be made. There are a number of factors which enter into this selection.

(1) *Drainage.* In the first place the plant should be located so that there is good drainage in as many directions as possible. If there is any stream nearby it should be ascertained whether the proposed site is above flood level. This may require considerable investigation if there are no written records about the area, such as might be the case in sparsely settled regions as West Texas. This information often can be obtained from ranchers or farmers who have lived in the vicinity for a number of years. It is often the rule in dry climates that when rainfall does occur it comes in heavy downpours within very short periods.

(2) *Cooling of Plant Water.* If the climate is such that wind is needed for cooling the plant water, the site should be located on the top of a hill. In certain areas where the average wind velocity is high, such as in the Great Plains area of the United States, sufficient cooling usually can be obtained by placing the plant on a relatively low ground. In fact, the location of the plant on a hilltop in very windy country might not be so desirable because of the heavy loss of water from cooling towers. Recent improvements in water-cooling towers have resulted in the reduction of wind loss. These newer towers are equipped with better distribution systems and the sides are protected with vertical slats which cause the cooling air to take a zig-zag course in passing into and out of the tower. It is doubtful whether towers, so well protected from wind loss, will provide the same amount of cooling as the old open-type louvre towers, unless they are provided with special devices to make it possible to easily open up the air ducts on windless days. Since cooling is a major item in plant operation it is necessary to place the towers away from the other plant buildings, and to set them perpendicular to the prevailing summer wind.

(3) *Miscellaneous.* The plant site should be fairly level, especially where the engine room is placed, in order to save excavating and filling costs sometimes required to keep the engines all on one floor level. The topography of the land especially in hilly or mountainous country, may determine the position of the engine room. In level regions it is preferable to set the engine room at right angles to the prevailing summer wind so as to give the air a free sweep through the room. This arrangement gives much lower engine room temperatures, which at their best are too high during July and August for comfortable working conditions. It is also more desirable to have the compressor ends of the machinery toward the windward side of the building. For example in Oklahoma where the summer wind is predominantly in the south the engine rooms which have compressor ends on the south side are always cooler, since the heat from the engines is swept out of the north side of the building. Conversely in winter, a cold north wind will force the heat generated by the engines to pass across the engine room and keep the room comfortably warm.

When gasoline plants are located some distance from towns it is customary for the companies to provide dwellings which are rented to their employees at nominal rates. These houses should be placed as near the plant as possible but far enough away to be safe in case of fire or explosion. Two hundred yards should be a safe distance for dwellings, provided they are so located that leakage of oil or gasoline from the plant cannot drain toward the houses. Gasoline storage tanks of the horizontal cylindrical type should not be set in such a way that either head of the tank is pointing toward the plant or the dwellings. Whenever horizontal tanks explode they invariably hurl themselves in a longitudinal direction just like a projectile. If the particular lease on which the plant is to be located has not been drilled, the plant and the dwellings should be so located that they will not be in the road of any oil wells which may be drilled on the lease in the future. Figure 1 shows the proper location of a plant site on an undeveloped 40-acre lease.

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[2]Katz, D. E., The Oil Weekly, Oct. 14, 1935.
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Continuous Acid Treatment of

Cracked Distillates

PART II

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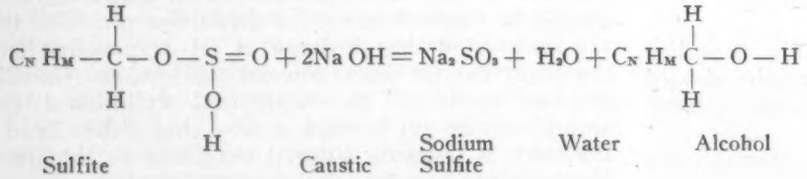
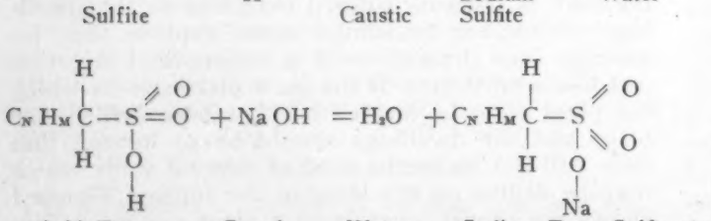
SLUDGE REMOVAL

AFTER the cracked distillate has been contacted with the desired amount of acid, the problem of removal of excess acid before neutralization arises.

If a high acid content remains in the oil a large amount of caustic will be necessary for neutralization, and caustic prices are considerably higher per equivalent weight than are acid prices, so that the caustic loss is important even though the loss of acid might be deemed inconsiderable. Of even more importance, however, is the need for minimizing acidity of the oil before neutralization on account of stability of the finished product. Instalibity will be caused from hydrolysis or saponification of acid esters in the acid oil upon neutralization and the amount of saponification depends to a great extent on the amount of acidity present in the oil layer before neutralization. (The terms "hydrolysis" and "saponification" are used in a loose sense because reactions occurring are so complex that most of them defy classification. Nevertheless the reactions do resemble saponification and hydrolysis and some of them are undoubtedly of this type. Therefore the terms have been drafted to serve the purpose of description.) In addition to these hydrolysis reactions, sodium salts of the sulfonic acids are formed upon neutralization, and many of these salts are more soluble in the oil layer than in the caustic phase. Some simple examples of possible reactions are shown below.





In the above reactions it will be noted that the end products of the neutralization reactions contain oxygen and sometimes sodium. It is this type product which is undesirable in the treated distillate after the neutralization. In minimizing the formation of oxygenated compounds the first step is to secure efficient settling of the sludge from the acid oil before the neutralization process. Necessary sizes for settlers vary according to the activity of the raw distillate and how it "takes" the acid, as well as upon the density, viscosity, and temperature of the oil and sludge. By laboratory experiments the approximate length of time necessary to secure good settling can be determined for the distillate in question. Titration of the mixture of distillate and sludge is the best way to determine the acidity of the mixture. Also if certain physical properties of the oil and sludge are known, then the quantity of suspended sludge remaining in the oil layer after any given time can be calculated by means of equations such as "Stokes Law." This calculation tells nothing of the amount of combined acid present and laboratory analysis is the only way to arrive at this value. Combined acid cannot be settled out however, so the calculation of suspended acid is the only relevant quantity needed for settler design. "Stokes Law" is expressed mathematically by the equation:

$$u = \frac{2R^2(D - D_o)g}{9n}$$ where

u is velocity of fall in still liquid.
R the radius of droplets.
D the density of the sludge particles.
D_o the density of the oil medium.
g the attraction of gravity, and
n the absolute viscosity of the oil.

There are other equations which are used for special cases based on laboratory determinations, but it is doubtful if an expression has been devised which will fit all cases as closely as "Stokes Law." By means of the equation it is possible to calculate the settler to give any desired degree of settling. It should be noted that u, the velocity of droplet fall in the above equation, is based on a still liquid, whereas the flow of the liquid in the settler may be either upwards or downwards. In either case a correction must be applied to give the "effective velocity of settling." Consideration of this point brings the realization of another fact which is not generally recognized in the construction of many treating plants.

Theoretically, the most efficient settler would be a very flat one where the mixture to be settled would

enter uniformly along one side of the settling basin, and either flow horizontally or downward to the opposite side of the settler where it would make its exit. Practically this kind of a settler in a refinery is not very easy to construct, most vessels available for settling chambers being cylindrical. By consideration of elementary principles it is easily determined that placing the vessel horizontally is to be preferred to the vertical position, for since the effective velocity of fall in Stokes equation is "u" minus the upward velocity of oil flow, the advantage of the horizontal settler will be directly proportional to the ratio of length to width of the settler above the point of entry of the oil-acid mixture. Calculation of the effectiveness of cylindrical settlers placed in various angles is so complicated that it will not be made here, but the maximum and minimum cases are the horizontal and vertical positions, for in the first case the upward velocity of oil flow is at a minimum and in the case of a vertical filter the upward velocity is at its maximum, so that the value to be subtracted from the "u" term in Stokes Law becomes a minimum in the first case and a maximum in the latter. Furthermore in a horizontal settler the horizontal length of travel of a sludge particle is much greater than in the vertical position, so that a smaller downward velocity will give the same settling efficiency as a higher downward velocity in a vertical settler. This amounts to saying that in the case of horizontal settlers the last particles to be settled out before the oil leaves the settler will be smaller than in the case of the vertical settler. This of course is the measure of settled efficiency. Another point worthy of mention is that the point of entry of the oil-acid mixture should be below the midpoint of a horizontal cylindrical settling vessel. Baffles should be used to insure a maximum length of travel of the oil on its way through the vessel, but in the construction of the baffles care should be taken not to leave projections and ledges upon which deep layers of sludge would be apt to accumulate. This point has been mentioned previously and is quite important in securing a finished product as free as possible from oxygenated material. Also when the settler is operated intermittently operators should be instructed to carefully draw off the sludge layer after a shutdown so that the oil in the system at the time of shutdown will not become sulfonated during the down period and contaminate the next batch of distillate treated.

With a highly cracked distillate only an incomplete separation of suspended sludge is attained even with a very large settler, and in order to further reduce acidity of the oil, percolation filters are sometimes used. Fullers earth was one of the filtering agents tried, and did give excellent results from the point of view of acid removal. Due to the activity of the earth, however, operating cycles were short and renewal of spent earth expensive. Substitutes have proved themselves to be quite successful, notably sand. These give long-life operation and give a fairly good separation of sludge from oil. Unlike fullers earth, sand has no adsorptive activity and the filtering action is purely mechanical, the mechanism apparently being one of first stopping a particle of suspended sludge at a pore too small for the passage of the sludge particle, and then combining this particle with another one to give a droplet which will settle out readily at the bottom of the filter where space is provided for this purpose.

Reduction in acidity of about 400 percent is attained by the use of one of these sand filters, and caustic savings will be sufficient to pay for the cost of installation and cleaning. Sand must be renewed from time to time, the average life per cubic foot of sand being about 550 barrels throughput. Grading of sand particle sizes is usually practiced in order to provide for pressure drop and for sludge particles to settle out, so that at the bottom of the filter, coarse gravel or rocks are used. Below the rocks is an open space for sludge removal and settling.

Centrifuges have been used long and successfully in the treatment of lubricating oils but until recently mechanical and corrosion problems have prevented their adaptation to the neutralization of acid-treated distillates. There are now in operation, however, batteries of centrifuges separating sludge from distillate just as there are other batteries engaged in dewaxing lubricating oils. Corrosion problems have been successfully dealt with by the use of newly developed alloys, and the centrifuge appears to have assumed a permanent important position in sludge acid removal. Theoretically the centrifuge appears to be the best of any method for the removal of suspended sludge. Not only are caustic costs greatly reduced, but the quality of the distillate is better due to the lower quantity of sulphonic acid, and sulphite salts present at the time of neutralization. Higher installation costs of the centrifuge are greatly offset by decreased corrosion and cleaning costs on the rerun stills. Sulfur dioxide liberation at the rerun stills is minimized and stability of the finished gasoline is improved.

As yet, the initial costliness of centrifuge installation has retarded the immediate adoption of this valuable tool, but due to the many attractions of the centrifuge, it is predicted that future installations will become the rule rather than an interesting experiment. Compactness of the centrifuge as compared to a settling and filtering system is also attractive, especially so to those refineries situated in large cities where space is usually at a premium.

NEUTRALIZATION

As previously explained, the sodium salts, and the oxygenated compounds which are formed upon neutralization of acid oil and acid sludge, are harmful to the quality of the finished distillate and for this reason many processes have been conceived with the idea of eliminating some or all of the objectionable neutralization products.

One of the most widely used methods is a water wash used prior to the caustic neutralization. In spite of a wide use, this method has not been found to be particularly effective in improving the quality of the distillate, but does decrease the amount of caustic necessary for neutralization because of the strong affinities of sulfuric acid and water. At the same time some benefit in quality of distillate is obtained because of a fairly high solubility of acid esters in water. Undesirable hydrolysis reactions occur, however, just as they do upon caustic neutralization, and, aside from the caustic savings obtained it is doubtful

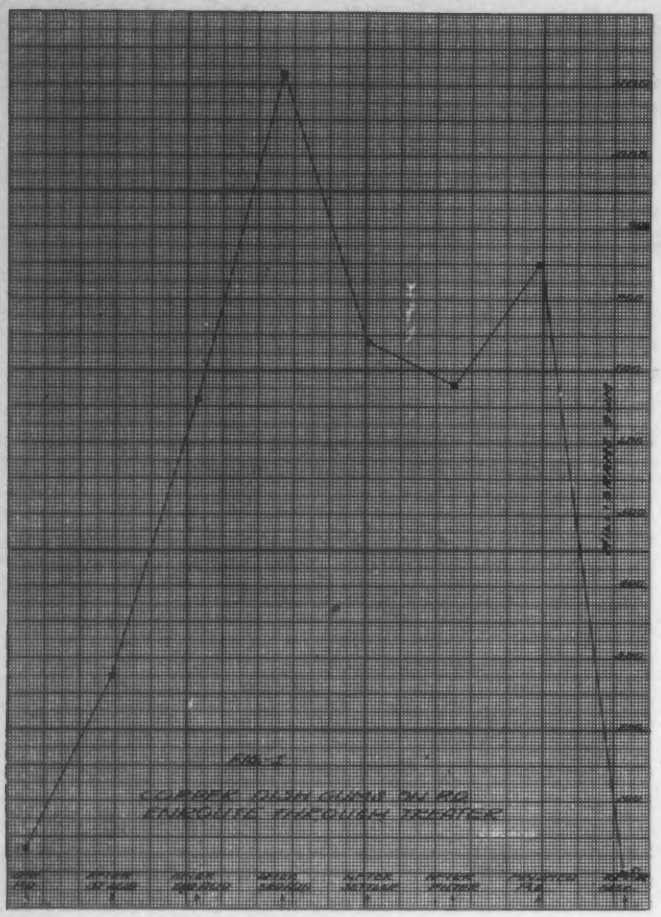


FIGURE 1

if a water wash is desirable. Adoption of the wash will depend therefore upon local caustic prices.

There is a good chance to greatly reduce the amount of unstable material thrown into the oil upon neutralization by investigation of the preferential solubilities of esters, sulfonates, alcohols, and allied oxygenated compounds in caustic of various strengths in the presence of distillates. It appears possible and reasonable to suppose that with a variation of caustic strength, there will be some variation of the solubility of oxygenated and sulfonated organic compounds in the caustic. So far there has been little research work done on this problem although Pilat, Sereda, and Szandowski[2] published in 1933 a valuable dissertation upon the solubilities of α, β and γ forms of sulfonates in various solvents.

Another potential remedy exists, the possibilities not having been the subject of appreciable research, namely the use of another alkali for neutralization in place of the usual sodium hydroxide. The cost of potassium hydroxide is not prohibitive if it were found to be better than sodium hydroxide. Likewise calcium hydroxide (lime) is a cheap chemical, and in view of the usual lower solubilities of calcium sulfates as compared to sodium or potassium sulfates the probability is that an improvement might be effected by neutralizing with a suspension of lime rather than the sodium hydroxide solution. Barium sulfate is very insoluble in water, and a barium hydroxide wash after neutralization might be effective. (On account of the high cost of barium salts, a wash before neutralization would probably be prohibitively costly.)

These possibilities have been mentioned because of the real need of some investigation of the effects obtained by the use of various strengths and composition of neutralizing solutions. If good solutions to a few of the problems existing in acid treating processes are found, it is possible that inhibitors might lose some of their present attractions. With the existing conditions, however, inhibitors appear here to stay, and it is probable that their use will be increased rather than decreased in the future.

In mixing caustic with the acid-oil usual custom is to use a circulation pump and a mixing nozzle or length of pipe with staggered baffles. A jet may be successfully used as was recommended for the mixing of acid with the oil. Objections to a very fine subdivision of the acid was one of the points favoring a jet for acid-oil mixing, and this feature is not particularly important in the neutralization reaction. Therefore a pump, mechanical agitator, or jet may be used for this process.

Little apparent difficulty is experienced in securing a good settling in the caustic settler except in the case of very highly unsaturated cracked distillate where emulsions are sometimes encountered. Even though the settling obtained in the caustic settler does appear satisfactory to the inexperienced observer, yet there usually is a certain amount of suspended caustic in the oil leaving. In this suspended material there is not only free NaOH, but in addition

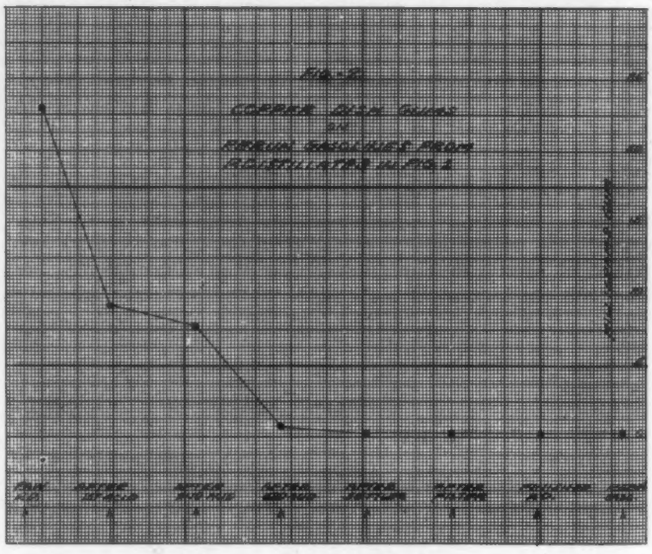


FIGURE 2

there are many molecules of sulfonated organic compounds which have been extracted into the caustic layer. If the distillate from the caustic settler goes directly to the rerun unit decomposition of these organic compounds will occur with the liberation of sulfur dioxide, free sulfur and even sulfuric acid. In many rerun units a heavy deposit of coke is sometimes found even though the maximum temperature in the still had never exceeded 400 or 450 °F. In a steam still, coke deposition or sulfur dioxide liberation does not occur to an appreciable extent, but saponification and hydrolysis is greatly increased in the steam stilling with resultant increase in the alcohols and oxygenated material leaving as finished product.

Sand filters will successfully remove this suspended caustic and insure a dry treated distillate charge to the rerun units and only a small filter is needed for quite large throughputs, the filter merely

acting as an agglomerator for the suspended caustic particles. In some plants there is a large enough tankage so that the treated distillate is pumped to an idle tank for further settling. With this arrangement a sand filter is still desirable, though not nearly so necessary as when the treated distillate from the settler goes directly to the rerun unit.

OPERATING FACTORS

Some design factors of pressure distillate treaters having been discussed in the foregoing pages, it now remains to enumerate the things which a well designed acid treating plant will accomplish.

First and foremost, the stability of the finished gasoline must meet the rigid requirements now existent for first class gasolines. Accelerated gum tests and the length of induction periods are now standard tests in all laboratories. Gasolines containing appreciable amounts of oxygen will not meet these rigid requirements and while the mechanism of the deleterious reactions are not definitely known, it is known that oxygenated compounds cause the formation of acidity by oximation of sulfur present in the gasoline. Acidity in a gasoline will cause polymerization and gum formation in a finished gasoline, just as an acid treatment of the raw distillate polymerizes the most unstable constituents present.

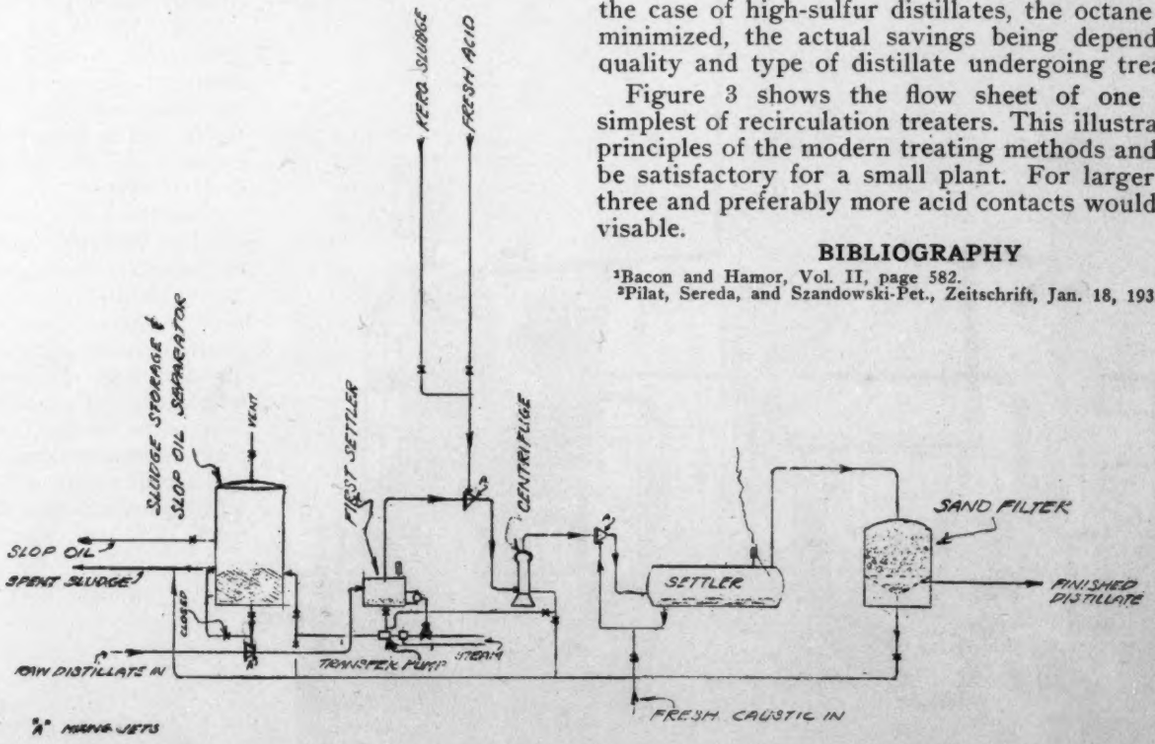
Copper cup gum tests, notoriously fallible as an indication of long-time stability do give a fairly good measure of the gum initially present in a gasoline, and of the tendency for the gasoline to immediately form a heavy deposit of gum. Figure 1 shows the copper dish gums on a 420 end-point cracked distillate as it passes through a three-stage acid treater with sludge recirculation. It will be noted from the gum increase on the distillate in the three acid contacts, that about an equal amount of polymerization is being secured on each contacting, which is desirable. The abrupt decrease of the gum content through the settler is indicative also of good operation as it shows a dragging down of the heaviest of the polymerized molecules with the acid sludge. Only a slight further decrease is noted through the sand filter, but at the time the samples were taken, the sand filter had been in operation for a considerable time and the filter was badly in need of cleaning.

Increase of gum content after neutralization as shown on the figure, is evidence of the formation of sodium sulfonate salts and allied compounds, the undesirability of this reaction having been discussed previously. Finally the gum content of the rerun gasoline shows the rejection of the polymerized and sulfonated compounds into the rerun still bottoms to produce a finished gasoline of low gum content.

Figure 2. shows the rerun gasolines obtained from the distillate at each point on its way through the treater as shown in Figure 1. Gums shown on Figure 2 are about as would be expected from a three-stage acid treater. In the copper-cup test 2 mg. gum can be considered a check determination, so that after the third acid treat no further reduction in copper-dish gum was obtained. Oxygen bombs for induction period determinations on these seven samples were unfortunately not available at the time the samples were taken.

With acid treaters designed by the principles outlined in the foregoing discussion material savings in acid consumption are easily obtained when compared to the older design treaters. In the case of low-sulfur distillates, acid consumption usually can be cut to one third of that previously necessary while in the case of high-sulfur crudes the savings in pounds-acid-per-barrel-distillate are more although the percentage saving is less. Along with decrease in acid consumption comes a very worth while saving in treating losses and in octane depreciation. The latter factor in the case of low-sulfur distillates becomes almost negligible. Certainly the average loss in octane does not exceed one-fourth of an octane number, which in view of the uncertainties inherent in the method of octane determinations is not significant. In the case of high-sulfur distillates, the octane loss is minimized, the actual savings being dependent on quality and type of distillate undergoing treatment.

Figure 3 shows the flow sheet of one of the simplest of recirculation treaters. This illustrates the principles of the modern treating methods and would be satisfactory for a small plant. For larger plants three and preferably more acid contacts would be advisable.



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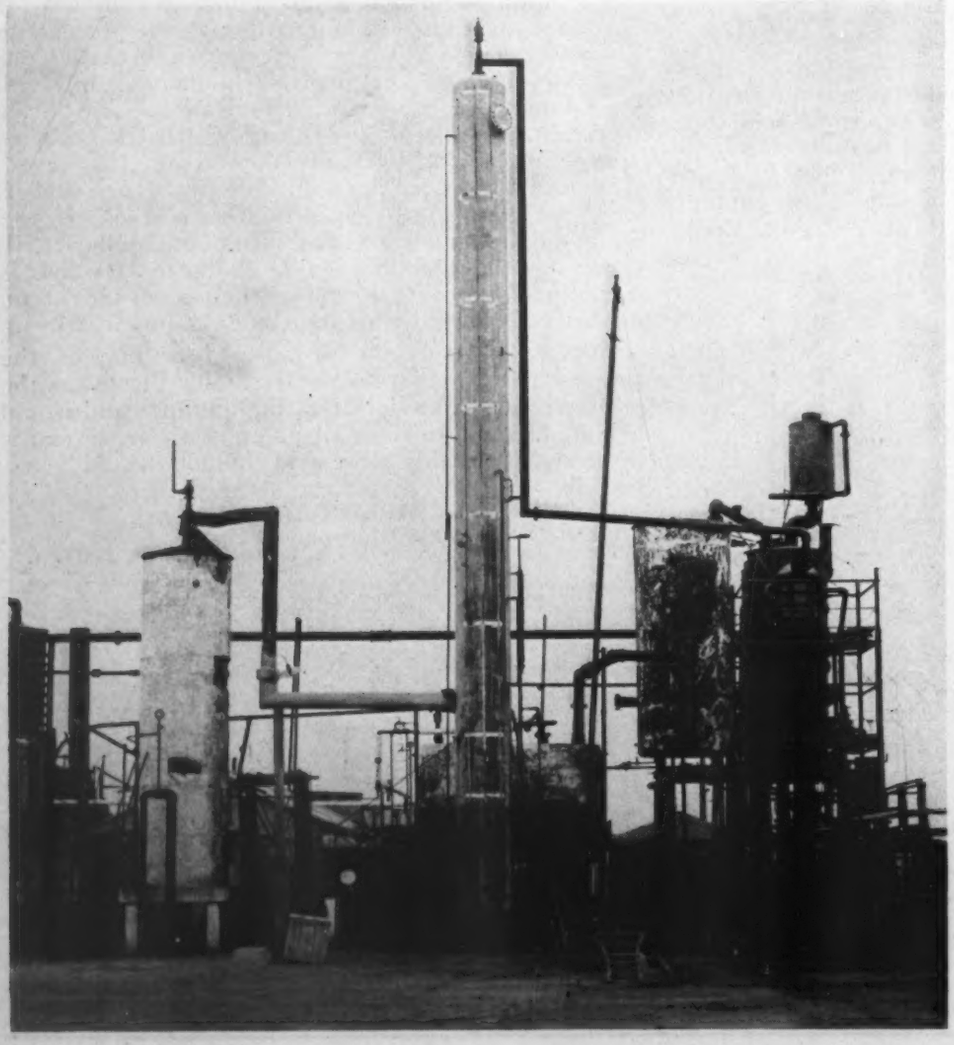
Lakeview Plant *Specializes* in Three Products

LAKEVIEW Oil & Refining Company manufactures only three products in its refinery at Maricopa. Crude oil from wells located on leases surrounding the plant, having a gravity of 24/26 A.P.I., is pumped through heat exchangers by duplex reciprocating pumps, where the hot residuum from the plant flows in counter current to the fresh crude charge.

The heated oil is released from the exchangers to a flash tower where, at a temperature of 210°F., a portion of the vapors are removed. It is picked up from the base of the preliminary flash column by a pump similar to the one used in the first instance, and pumped directly to the pipe still. This unit is a new piece of refining equipment recently installed and was designed by company engineers. It contains 2400 feet of 2½-inch tubes.

The transfer temperature of the oil leaving the outlet of the last bank of coils in the tube still is held at 500°F. and is flashed immediately in the main evaporator column. The vapors from the flash column and the preliminary distillation tower are thrown together after they leave the main fractionator and are condensed together. The top of the fractionator is held at 280°F. by the use of temperature control instruments controlling the volume of reflux returning to the top of the column.

About 30 percent of the original charge is removed as motor fuel, having an end-point of about 410°F. A stove oil cut is also removed from the column, being taken from the tower at the seventh plate. As the vapors from the flash column enter the fractionator above the third plate, a good selective cut may be taken from the seventh plate without throwing the column out of balance.



The fuel fraction removed from the base of the flash column has a gravity of about 17° A.P.I. and is pumped through enclosed tubular exchangers to obtain the required heat on the fresh crude charge being pumped to the plant, and then to storage.

Gasoline and stove oil are handled by truck and trailer to markets throughout the San Joaquin valley and the Los Angeles Basin. The plant is not large, and consequently does not require a large force of operators. It is handled by three shifts, a plant superintendent, chemist and a utility man who fills in when the shifts are changing tour.